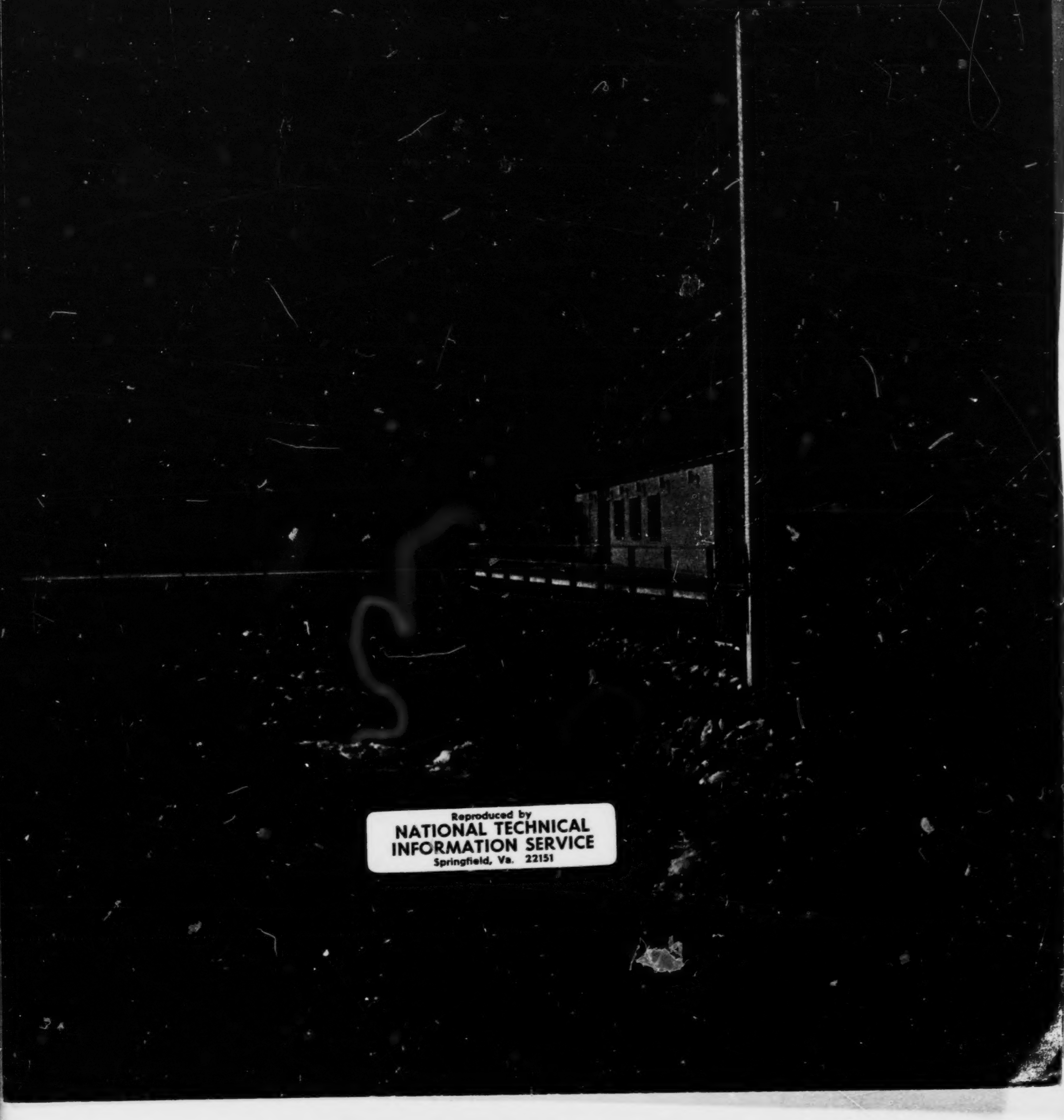
PB 203 674



Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

COMPUTER SIMULATION OF THE HYDROLOGIC-SALINITY FLOW SYSTEM WITHIN THE UPPER COLORADO RIVER BASIN

by

M. Leon Hyatt
J. Paul Riley
M. Lynn McKee
Eugene K. Israelsen

The work reported by this final report was supported primarily with funds provided by the United States Department of the Interior, Federal Water Quality Administration under P.L. 89-787, Demonstration Grant Number 16090-DVU, Contract Number 12-14-100-9715(41), Investigation Period-June 1, 1967 to December 31, 1969.

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah
July 1970

PRWG54-1

263

ABSTRACT

Changes in the hydrologic equilibrium of a river basin resulting from resource development also produce changes in the quality pattern. Since the burden of quality maintenance must be shared by users (just as are quantities) predictions are needed for quality changes which might result from contemplated development at any specified location within the river system. This study reports the development of a computer simulation model of the water and salt flow systems within the Upper Colorado River basin.

Because of the close relationship between the hydrologic and salinity flow systems, an understanding of the hydrologic system is essential to successful management of the salinity system. In this study development of a hydrologic model is based on water budgeting or accounting procedures, in which available data on historical water flows, municipal and industrial uses, and the demands of agriculture are used. The salinity dimension is then added, and the joint hydrosalinity model is verified (calibrated and tested) by comparing computed and observed output values.

The utility of the model is demonstrated by applying it to a particular subbasin of the San Juan River and predicting the effects on downstream water quantity and quality of developing a large irrigation project within the area.

TABLE OF CONTENTS

Chapter Page

I INTRODUCTION 1

II COMPUTER SIMULATION OF SYSTEMS 5

Simulation Techniques 5
Utilization of Computers for Simulation 5

Digital computers 6
Analog computers 6
Hybrid computers 6

Modeling Approach 6
Time and Spatial Considerations 7

III THE HYDROLOGIC MODEL 9

River and Tributary Inflows 9

Surface inflow 9
Subsurface inflow 12
Groundwater inflow 12
Total inflow 12

Precipitation 13

Average precipitation 13
Forms of precipitation 13
Precipitation abstractions 13

Temperature 14
Snowmelt 14
Canal Diversions 15
Available Soil Moisture 15

Sources of available water 16
Available soil moisture quantities 16

Infiltration 17
Evapotranspiration 17

Methods of direct measurement of evapotranspiration rate 17
Methods for computing evapotranspiration rate 17
Effects of soil moisture on evapotranspiration 19
Effects of slope and elevation on evapotranspiration 21

Deep Percolation 21
River Outflow 21

ACKNOWLEDGMENTS

This publication represents the final report of a project which was supported primarily with funds provided by the Federal Water Quality Administration of the United States Department of the Interior as authorized under Public Law 89-787. The work was accomplished by personnel of the Utah Water Research Laboratory in accordance with a research proposal which was submitted to the Federal Water Quality Administration. The valuable and continuing support of Dr. Jay M. Bagley, Director of the Utah Water Research Laboratory, and several members of his staff is gratefully acknowledged.

The authors express gratitude to Mr. Marshall B. Rainey and several members of his staff in the Colorado River-Bonneville Basins Office of the FWQA in Denver, Colorado, who willingly provided water quality data and helpful suggestions throughout the course of the study. In particular, appreciation is expressed to Mr. Richard Sotiros who was the project officer, and in this capacity he provided helpful advice and many constructive comments during the study.

Because of the large magnitude and extensive scope of this project, the assistance of many organizations and agencies was sought, and in every case help was generously given. These organizations include the Soil Conservation Service, the U.S. Bureau of Reclamation, the U.S. Geological Survey, the Upper Colorado River Water Commission, State Engineers' Offices, the State Water Resources Divisions, and various other government agencies from each of the Upper Basin States. The data and constructive comments provided during the study by personnel from these organizations were invaluable to the success of the project.

M. Leon Hyatt
J. Paul Riley
M. Lynn McKee
Eugene K. Israelsen

TABLE OF CONTENTS (Continued)

Chapter Page

IV MODEL OF TOTAL DISSOLVED SOLIDS FLOW 23

General Characteristics of Water Quality 23
River and Tributary Inflows 26

Surface inflow 26
Groundwater inflow 28
Total inflow 28

Precipitation 28
Temperature 29
Canal Diversions 29
Effects of Dissolved Solids on Agriculture 29

Infiltration 30
Plant responses to salinity 30
Evapotranspiration 31
Salt balance 31

Return Flow 32

Surface runoff and interflow 32
Deep percolation 33

Natural Inbasin Salinity Contribution 33
Subbasin Outflow 36

V ASPECTS OF COMPUTER PROGRAMMING AND VERIFICATION OF THE HYDROLOGIC AND SALINITY FLOW SYSTEMS 39

Programming Characteristics of the Analog Computer 39

Magnitude scaling 39
Time scaling 40
Time delays 40
Input of voltages to the computer 40

Programming the Hydrologic Flow System 40

Snowmelt process 40
Evapotranspiration calculation 40
Diverted and return flows 43
The unsaturated soil moisture regime 43
Deep percolation 43
Basin inflow 44
Basin outflow 44

Programming the Combined Hydrologic-Salinity Flow Systems 44
Verification of the Hydrologic and Salinity Models 46

VI APPLICATION OF THE COMPUTER MODEL TO THE HYDROLOGIC-SALINITY FLOW SYSTEM OF THE UPPER COLORADO RIVER BASIN 49

Description of Basin 49

TABLE OF CONTENTS (Continued)

Chapter . . . Page

IV MODEL OF TOTAL DISSOLVED SOLIDS FLOW . . . 23

General Characteristics of Water Quality . . . 23
River and Tributary Inflows . . . 26

Surface inflow . . . 26
Groundwater inflow . . . 28
Total inflow . . . 28

Precipitation . . . 28
Temperature . . . 29
Canal Diversions . . . 29
Effects of Dissolved Solids on Agriculture . . . 29

Infiltration . . . 30
Plant responses to salinity . . . 30
Evapotranspiration . . . 31
Salt balance . . . 31

Return Flow . . . 32

Surface runoff and interflow . . . 32
Deep percolation . . . 33

Natural Inbasin Salinity Contribution . . . 33
Subbasin Outflow . . . 36

V ASPECTS OF COMPUTER PROGRAMMING AND VERIFICATION OF THE HYDROLOGIC AND SALINITY FLOW SYSTEMS . . . 39

Programming Characteristics of the Analog Computer . . . 39

Magnitude scaling . . . 39
Time scaling . . . 40
Time delays . . . 40
Input of voltages to the computer . . . 40

Programming the Hydrologic Flow System . . . 40

Snowmelt process . . . 40
Evapotranspiration calculation . . . 40
Diverted and return flows . . . 43
The unsaturated soil moisture regime . . . 43
Deep percolation . . . 43
Basin inflow . . . 44
Basin outflow . . . 44

Programming the Combined Hydrologic-Salinity Flow Systems . . . 44
Verification of the Hydrologic and Salinity Models . . . 46

VI APPLICATION OF THE COMPUTER MODEL TO THE HYDROLOGIC-SALINITY FLOW SYSTEM OF THE UPPER COLORADO RIVER BASIN . . . 49

Description of Basin . . . 49

TABLE OF CONTENTS (Continued)

Chapter | Page

Location . . . 49
Population . . . 49
River development . . . 49
Topography . . . 51
Climate . . . 51
Vegetation . . . 51
Geology . . . 51
Soils . . . 52
Compacts and treaties . . . 52
Hydrology . . . 52
Water quality . . . 53
Suitability for use . . . 63

Subbasin Development . . . 63
Data Evaluation . . . 63

The model boundaries . . . 63
Meteorological data . . . 64
Canal diversions . . . 65
Vegetative distribution . . . 66
Soil moisture capacity . . . 66
Water quality data . . . 66

Simulation of the White River Subbasin - An Illustrative Example . . . 67
General description of the White River subbasin . . . 67
Model development . . . 68

VII SYNOPSIS OF THE MODEL SUBBASINS WITHIN THE UPPER COLORADO RIVER DRAINAGE . . . 77

Green Division . . . 77

New Fork River subbasin . . . 77
Green River above La Barge, Wyoming, subbasin . . . 77
Green River above Fontenelle Reservoir subbasin . . . 78
Big Sandy Creek subbasin . . . 78
Green River above Green River, Wyoming, subbasin . . . 78
Blacks Fork River subbasin . . . 78
Green River above Flaming Gorge Dam subbasin . . . 79
Little Snake River subbasin . . . 79
Yampa River subbasin . . . 79
Green River above Jensen, Utah, subbasin . . . 80
Ashley Creek subbasin . . . 80
Duchesne River above Duchesne, Utah, subbasin . . . 80
Duchesne River above Randlett, Utah, subbasin . . . 80
White River subbasin . . . 83
Green River above Ouray, Utah, subbasin . . . 83
Price River subbasin . . . 83
Green River above Green River, Utah, subbasin . . . 83
San Rafael River subbasin . . . 83

Grand Division . . . 84

Colorado River above Hot Sulphur Springs, Colorado, subbasin . . . 84
Eagle River subbasin . . . 84
Colorado River above Glenwood Springs, Colorado, subbasin . . . 84

TABLE OF CONTENTS (Continued)

Chapter Page

Roaring Fork River subbasin 85
Colorado River above Plateau Creek subbasin 85
Plateau Creek subbasin 85
Gunnison River above Gunnison, Colorado, subbasin 85
Gunnison River above the North Fork Gunnison River subbasin 86
Uncompahgre River subbasin 86
Gunnison River above Grand Junction, Colorado, subbasin 86
Colorado River above Colorado-Utah stateline subbasin 87
San Miguel River subbasin 87
Dolores River subbasin 87
Colorado River above Cisco, Utah, subbasin 87

San Juan Division 88

San Juan River above Arboles, Colorado, subbasin 88
San Juan River above Archuleta, New Mexico, subbasin 88
Animas River subbasin 88
San Juan River above Farmington, New Mexico, subbasin 91
LaPlata River subbasin 91
San Juan River above Shiprock, New Mexico, subbasin 91
San Juan River above Bluff, Utah, subbasin 91
Colorado River above Lee Ferry, Arizona, subbasin 92

A Summary of Results from the Subbasin Hydro-Salinity Models 92

VIII SIMULATION AS A MANAGEMENT TOOL 97

Management Alternatives 97
Evaluation of a Proposed Irrigation Project 97

Proposed development project 97
General description of basin 99
Analog hydro-salinity model of the basin 100
Verification of analog model 101
Modeling average data 103
Predicted effects of project 105
Alternative variations within project 110
Alternative diversion schemes 112

IX RECOMMENDED RESEARCH NEEDS FOR MODEL IMPROVEMENT 115

X SUMMARY AND CONCLUSIONS 117

SELECTED REFERENCES 121

APPENDICES 125

LIST OF FIGURES

Figure Page

3.1 Flow diagram for hydrologic flow system 10

3.2 Average extraction of soil moisture by plant roots between irrigations (Israelsen and Hansen, 1967) 16

3.3 Crop growth stage coefficient curve for alfalfa 20

3.4 Crop growth stage coefficient curve for grass-pasture 20

4.1 Flow diagram for the salinity flow system 24

4.2 Relation of moisture tension to moisture percentage at different soil salinity levels (Redrawn from Wadleigh and Ayers, 1945) 30

4.3 Interchange or recirculation plot for the White River subbasin 35

5.1 Analog computer wiring diagram for the hydrologic flow system 41

5.2 Analog computer wiring diagram for the hydrologic and salinity flow system 47

6.1 Upper Colorado River basin showing main tributary divisions and hydrologic subbasins 50

6.2 Mean annual water flow rates, Green division 54

6.3 Mean annual water flow rates, Grand division 55

6.4 Mean annual water flow rates, San Juan division 56

6.5 Average salt content in surface waters, Green division 57

6.6 Average salt content in surface waters, Grand division 58

6.7 Average salt content in surface waters, San Juan division 59

6.8 Mean annual salt flow rates, Green division 60

6.9 Mean annual salt flow rates, Grand division 61

6.10 Mean annual salt flow rates, San Juan division 62

6.11 Comparison of computed and observed monthly discharge of water and salt from the White River Basin for 1964 and 1965 73

6.12 Computed available soil moisture in the agriculture area of the White River subbasin for 1964 73

LIST OF FIGURES (Continued)

Figure **Page**

6.13 Rate of deep percolating flow of water from agriculture area of the White River subbasin for 1964 75

6.14 Rate of subsurface outflow of water at outflow monitoring points of the White River subbasin for 1964 75

6.15 Schematic diagram of estimated average annual hydro-salinity flow system of the White River Basin 76

7.1 Schematic diagram of the average hydro-salinity flow system, Green River division 81

7.2 Schematic diagram of the average hydro-salinity flow system, Grand River division 89

7.3 Schematic diagram of the average hydro-salinity flow system, San Juan division 93

8.1 Location map depicting the proposed irrigation development for the Navajo Indians in north western New Mexico 98

8.2 Comparison between the 1964 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico without the proposed project 102

8.3 Comparison between the 1965 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico without the proposed project 102

8.4 Comparison between the 1966 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico without the proposed project 106

8.5 Comparison between the 1931-60 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico without the proposed project 106

8.6 Comparison of the basin outflow hydrographs of water and salt for 1964 with and without the proposed irrigation development 108

8.7 Comparison of the basin outflow hydrographs of water and salt for 1965 with and without the proposed irrigation development 108

8.8 Comparison of the basin outflow hydrographs of water and salt for 1966 with and without the proposed irrigation development 109

8.9 Comparison of the basin outflow hydrographs of water and salt for 1931-60 with and without the proposed irrigation development 109

LIST OF FIGURES (Continued)

Figure		Page
A-1	New Fork River Basin and Green River above LaBarge, Wyo., hydrologic and salinity subbasins	A-3
A-2	Green River above Fontenelle Reservoir and Green River above Green River, Wyo., hydrologic and salinity subbasins	A-4
A-3	Big Sandy Creek Basin, hydrologic and salinity subbasins	A-5
A-4	Blacks Fork River Basin, hydrologic and salinity subbasin	A-6
A-5	Green River above Flaming Gorge Dam, hydrologic and salinity subbasin	A-7
A-6	Little Snake River Basin, hydrologic and salinity subbasin	A-8
A-7	Yampa River Basin, hydrologic and salinity subbasin	A-9
A-8	Green River above Jensen, Ut., hydrologic and salinity subbasin	A-10
A-9	Ashley Creek Basin and Green River above Ouray, Ut., hydrologic and salinity subbasins	A-11
A-10	Duchesne River above Duchesne, Ut. and Duchesne River above Randlett, Ut., hydrologic and salinity subbasins	A-12
A-11	White River Basin, hydrologic and salinity subbasin	A-13
A-12	Price River Basin and San Rafael River Basin, hydrologic and salinity subbasin	A-14
A-13	Green River above Green River, Ut., hydrologic and salinity subbasin	A-15
A-14	Colorado River above Hot Sulphur Springs, Colorado River above Glenwood Springs, and Eagle River Basin, hydrologic and salinity subbasins	A-16
A-15	Colorado River above Plateau Creek, Plateau Creek, and Roaring Fork River Basin, hydrologic and salinity subbasins	A-17
A-16	Gunnison River above Gunnison, Colo. and Gunnison River above North Fork Gunnison River, hydrologic and salinity subbasins	A-18
A-17	Gunnison River above Grand Junction, Colo. and Uncompahgre River Basin, hydrologic and salinity subbasins	A-19
A-18	Colorado River above Colo.-Ut. State Line and Colorado River above Cisco, Ut., hydrologic and salinity subbasins	A-20

LIST OF FIGURES (Continued)

Figure | Page

A-19 Dolores River Basin and San Miguel River Basin, hydrologic and salinity subbasins A-21

A-20 San Juan River above Archuleta, N. M. and San Juan River above Arboles, Colo., hydrologic and salinity subbasins A-22

A-21 Animas River Basin and La Plata River Basin, hydrologic and salinity subbasins A-23

A-22 San Juan River above Farmington, N. M., hydrologic and salinity subbasins A-24

A-23 San Juan River above Shiprock, N. M., hydrologic and salinity subbasin A-25

A-24 San Juan River above Bluff, Ut., hydrologic and salinity subbasin A-27

A-25 Dirty Devil River Basin, hydrologic and salinity subbasin A-29

A-26 Colorado River above Hite, Ut., hydrologic and salinity subbasin A-30

A-27 Escalante River Basin and Colorado River at Lee Ferry, Ariz., hydrologic and salinity subbasins A-31

H-1 Computed and recorded water and salt outflow graphs of the New Fork River Basin H-9

H-2 Computed and recorded water and salt outflow graphs of Green River above LaBarge H-9

H-3 Computed and recorded water and salt outflow graphs of Green River above Fontenelle Dam H-10

H-4 Computed and recorded water and salt outflow graphs of Big Sandy Creek Basin H-10

H-5 Computed and recorded water and salt outflow graphs of Green River above Green River, Wyo. H-11

H-6 Computed and recorded water and salt outflow graphs of Blacks Fork River Basin H-11

H-7 Computed and recorded water and salt outflow graphs of Green River above Flaming Gorge Dam H-12

H-8 Computed and recorded water and salt outflow graphs of Little Snake River Basin H-12

H-9 Computed and recorded water and salt outflow graphs of Yampa River Basin H-13

H-10 Computed and recorded water and salt outflow graphs of Green River above Jensen, Ut. H-13

LIST OF FIGURES (Continued)

Figure **Page**

H-11 Computed and recorded water and salt outflow graphs of the Ashley Creek Basin H-14

H-12 Computed and recorded water and salt outflow graphs of the Duchesne River above Duchesne, Ut. H-14

H-13 Computed and recorded water and salt outflow graphs of the Duchesne River above Randlett, Ut. H-15

H-14 Computed and recorded water and salt outflow graphs of the White River Basin H-15

H-15 Computed and recorded water and salt outflow graphs of the Green River above Ouray, Ut. H-16

H-16 Computed and recorded water and salt outflow graphs of the Price River Basin H-16

H-17 Computed and recorded water and salt outflow graphs of the Green River above Green River, Utah H-17

H-18 Computed and recorded water and salt outflow graphs of the San Rafael Basin H-17

H-19 Computed and recorded water and salt outflow graphs of the Colorado River above Hot Sulphur Springs H-18

H-20 Computed and recorded water and salt outflow graphs of the Eagle River Basin H-18

H-21 Computed and recorded water and salt outflow graphs of the Colorado River above Glenwood Springs, Colo. H-19

H-22 Computed and recorded water and salt outflow graphs of the Roaring Fork River Basin H-19

H-23 Computed and recorded water and salt outflow graphs of the Colorado River above Plateau Creek H-20

H-24 Computed and recorded water and salt outflow graphs of the Plateau Creek Basin H-20

H-25 Computed and recorded water and salt outflow graphs of the Gunnison River above Gunnison, Colo. H-21

H-26 Computed and recorded water and salt outflow graphs of the Gunnison River above North Fork Gunnison R. H-21

H-27 Computed and recorded water and salt outflow graphs of the Uncompahgre River Basin H-22

H-28 Computed and recorded water and salt outflow graphs of the Gunnison River above Grand Junction, Colo. H-22

H-29 Computed and recorded water and salt outflow graphs of the Colorado River above Colo.-Ut. State Line H-23

LIST OF FIGURES (Continued)

Figure **Page**

H-30 Computed and recorded water and salt outflow graphs of the San Miguel River Basin H-23

H-31 Computed and recorded water and salt outflow graphs of the Dolores River Basin H-24

H-32 Computed and recorded water and salt outflow graphs of the Colorado River above Cisco, Ut. H-24

H-33 Computed and recorded water and salt outflow graphs of the San Juan River above Arboles, Colo. H-25

H-34 Computed and recorded water and salt outflow graphs of the San Juan River above Archuleta, N. M. H-25

H-35 Computed and recorded water and salt outflow graphs of the Animas River Basin H-26

H-36 Computed and recorded water and salt outflow graphs of the San Juan River above Farmington, N. M. H-26

H-37 Computed and recorded water and salt outflow graphs of the La Plata River Basin H-27

H-38 Computed and recorded water and salt outflow graphs of the San Juan River above Shiprock H-27

H-39 Computed and recorded water and salt outflow graphs of the San Juan River above Bluff, Ut. H-28

H-40 Computed and recorded water and salt outflow graphs of the Colorado River above Lee Ferry, Ariz. H-28

I-1 The effects on the water outflow hydrograph of 1965 from changing the rate of return of the deep percolating water to the surface system I-7

I-2 The effects on the salt outflow hydrograph of 1965 from changing the rate of return of the deep percolating water to the surface system I-8

I-3 The effects on the water outflow hydrograph of 1965 from changing the soil moisture capacity of the proposed irrigation project I-9

I-4 The effects on the salt outflow hydrograph of 1965 from changing the soil moisture capacity of the proposed irrigation project I-10

I-5 Effects on the water outflow hydrograph of 1965 from varying irrigation efficiency of the proposed project I-11

I-6 Effects on the salt outflow hydrograph of 1965 from varying irrigation efficiency of the proposed project I-12

I-7 Mean 1931-1960 salt outflow hydrograph with and without the exportation of New Mexico's allocated share of Colorado River water I-13

LIST OF TABLES

Table Page

3.1 Approximate readily available soil moisture storage capacity in inches per foot of depth of soil (McCulloch, Keller, Sherman, and Mueller, 1967) . . . 16

6.1 Subbasins with their associated hydrologic areas and years utilized in model development . . . 64

6.2 Hydrologic and salinity inputs to the White River Subbasin for 1964 . . . 69

6.3 Hydrologic and salinity inputs to the White River Subbasin for 1965 . . . 70

6.4 Single constant input parameters or coefficients for the White River subbasin . . . 72

8.1 Single constant input parameters or coefficients for management area above Shiprock, New Mexico . . . 104

B-1 Subbasin areas and location of irrigated acreage within the Green Division . . . B-3

B-2 Subbasin areas and location of irrigated acreage within the Grand Division . . . B-5

B-3 Subbasin areas and location of irrigated acreage within the San Juan Division . . . B-7

C-1 Weighted precipitation and temperature data for irrigated lands within the subbasins of the Green Division . . . C-3

C-2 Weighted precipitation and temperature data for irrigated lands within the subbasins of the Grand Division . . . C-8

C-3 Weighted precipitation and temperature data for irrigated lands within the subbasins of the San Juan Division . . . C-12

D-1 Gaging stations used in determining the inflow or discharge to subbasins of the Green Division . . . D-3

D-2 Gaging stations used in determining the inflow or discharge to subbasins of the Grand Division . . . D-7

D-3 Gaging stations used in determining the inflow or discharge to subbasins of the San Juan Division . . . D-12

E-1 Diversions for irrigation within the subbasins of the Green Division (acre-feet/month) . . . E-3

LIST OF TABLES (Continued)

Table		Page
E-2	Diversions for irrigation within the subbasins of the Grand Division (acre-feet/month)	E-4
E-3	Diversions for irrigation within the subbasin of the San Juan division (acre-feet/month)	E-5
E-4	Location and usable capacities of reservoirs in Green Division	E-6
E-5	Location and usable capacities of reservoirs in Grand Division	E-8
E-6	Location and usable capacities of reservoirs in San Juan Division	E-10
F-1	Vegetative distribution and acreages associated with subbasins in the Green Division	F-3
F-2	Vegetative distribution and acreages associated with subbasins in the Grand Division	F-4
F-3	Vegetative distribution and acreages associated with subbasins in the San Juan Division	F-5
F-4	Crop coefficients utilized in computation of potential consumptive use	F-5
H-1	Single constant input parameters or coefficients for subbasins within the Green Division	H-3
H-2	Single constant input parameters or coefficients for subbasins in the Grand Division	H-5
H-3	Single constant input parameters or constant for the subbasins in the San Juan Division	H-7
I-1	Hydrologic and salinity inputs to the management study basin-without proposed project 1964	I-3
I-2	Hydrologic and salinity inputs to the management study basin-without proposed project 1965	I-4
I-3	Hydrologic and salinity inputs to the management study area-without proposed project 1931-60	I-5
I-4	Hydrologic and salinity inputs to the management study area-with proposed project 1931-60	I-6

PARTIAL LIST OF SYMBOLS (Continued)

Symbol **Definition**

k_g = coefficient relating the rate of unmeasured groundwater inflow to a measured surface runoff rate

k_c = monthly coefficient which varies with type of crop and location

k_d = a constant determined by model verification representing the percentage of total outflow which leaves the basin as subsurface flow

k_p = percentage of surface flow allowed to interchange or recirculate through the stream alluvium or groundwater basin

k_s = a constant related to the rate of snowmelt

k_t = (0.0173t - 0.314) where t is mean monthly temperature in degrees F

k_u = coefficient relating the rate of unmeasured surface inflow to a gaged surface inflow rate

m = slope of line plotted on log-log paper

M_{cs} = root zone soil moisture storage capacity of water available to plants

M_{es} = limiting or threshold content of available water within the root zone below which the actual becomes less than the potential evapotranspiration rate

$M_s(t)$ = quantity of water available for plant consumption which is stored in the root zone at any instant of time

n = intercept on the y-axis (percentage axis) of a log-log plot

N_r = interflow rate

OF_r = total of overland flow (from irrigation applications at rates exceeding infiltration capacity rates) and interflow rates

p = monthly percentage of daylight hours of the year

P_r = gaged precipitation rate in the form of rain on the valley floor

Q_e = rate of water diversions from surface sources for use outside the boundaries of the subbasin. Exports to other drainage basins fall within this category.

Q_i = rate of total inflow to a particular subbasin

$Q_{ig}(u)$ = rate of total unmeasured inflow to the groundwater system

q_{is} = rate of surface runoff (either total measured tributary inflow or measured inflow from a representative tributary)

Q_{is} = rate of total surface inflow to the subbasin including both measured and unmeasured flows

PARTIAL LIST OF SYMBOLS

Symbol **Definition**

C_e = average salinity level of water exported from the subbasin

C_g = average water salinity level within the groundwater basin or stream alluvium of a hydrologic system

C_{ga} = average salinity level of the groundwater within the soil solution beneath the agricultural lands

$C_g(u)$ = average water salinity level associated with the unmeasured groundwater inflow to a subbasin

$C_i(m)$ = average measured concentration of total dissolved solids associated with inflowing surface waters to the system

C^j_{is} (m)= measured total dissolved solids concentration associated with the measured surface water inflow of tributary j

C^j_{is} (u) = estimated salinity concentration associated with tributary j

$C^Y_{is}(u)$ = a weighted average salinity concentration associated with the ungaged surface water

C_{og} = average salinity level of the subsurface water leaving the basin at the outflow point at a particular time

C_s = average water salinity level associated with the overland flow and interflow components of return flow from irrigation lands

Eff = water conveyance and application efficiency in percent

ET_{cr} = potential evapotranspiration rate

ET_r = actual evapotranspiration rate

f = the monthly consumptive use factor, a function of t and p

F_r = infiltration rate from the soil surface

G_r = deep percolation rate

k = a monthly coefficient which varies with type of crop and location

k_a = coefficient relating the rate of unmeasured surface inflow to a precipitation rate

k_b = coefficient relating the rate of unmeasured surface inflow to snowmelt rate

PARTIAL LIST OF SYMBOLS (Continued)

Symbol **Definition**

$q_{is}(m)$ = measured rate of surface inflow from a particular tributary area or stream

$Q_{is}(m)$ = rate of total surface measured or gaged inflow to the subbasin

$\Delta Q_{is}(m)$ = those streams for which measured water flow rates are available but for which quality data are not available

$Q_{is}(u)$ = estimated rate of unmeasured surface inflow

Q_{o} = total rate of outflow from the system

Q_{ob} = rate of outflow from the groundwater basin of ungaged subsurface inflows, $Q_{ig}(u)$, after routing

Q_{og} = rate of subsurface or groundwater outflow from the basin

Q_{oga} = rate of outflow from the groundwater basin of deep percolating waters, G_r, after routing

Q_{os} = rate of surface outflow from the subbasin

Q_{r} = monthly rate of surface water inflow, outflow, or average of inflow and outflow to a subbasin

RI_{h} = the radiation index for a horizontal surface at the same latitude as the particular watershed under study

RI_{s} = the radiation index on a surface possessing a known degree and aspect of slope

R_{tr} = limiting or threshold rate of surface water supply

S_r^{g} = rate of salt flow which deep percolates from the plant root zone

$S^{ig}_{r}(u)$ = rate of unmeasured salt inflow to a subbasin through the groundwater system

$S^{is}_{r}(m)$ = rate of salt inflow to a system associated with measured salinity levels and surface water inflows

$S^{is}_{r\Delta Q}(u)$ = rate of salt inflow associated with those surface streams for which hydrologic but not quality data are available

$S^{is}_{r}(u)$ = rate of salt inflow associated with surface waters for which hydrologic and quality data are not available

S_r^{NS} = rate of salt flow contributed from natural sources within the basin

S_r^{OF} = rate of salt flow returning from the agricultural area with overland flow and interflow

$S_r^{Q_{is}}$ = rate of salt flow associated with surface inflow waters to the subbasin

$S_r^{Q_{o}}$ = total rate of salt flow from a hydrologic system

PARTIAL LIST OF SYMBOLS (Continued)

Symbol **Definition**

$S_r^{Q_{og}}$ = rate of subsurface outflow of salt from the basin

$S_r^{Q_{os}}$ = rate of surface outflow of salt from the basin

$S_r^{W_{dr}}$ = rate of diverted salt inflow to the soil by seepage and infiltration

S_{wr} = rate of surface runoff during a particular time

t = mean monthly temperature in degrees F

T_a = surface air temperature in degrees F

T_b = assumed base temperature in degrees F at which melt begins to occur. In this study T_b was taken as being equal to 32 F.

u = monthly crop potential consumptive use in inches

W_{dr} = rate at which diverted water enters the soil through seepage and infiltration

W_{gr} = rate at which water is available at the soil surface

W_s = snow storage in terms of water equivalent

W_{sr} = estimated snowmelt rate in terms of water equivalent

W_{tr} = total rate at which water is diverted from the stream or reservoir

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

1. Report No.

2.

3. Accession No. W72-00084

4. Title
COMPUTER SIMULATION OF THE HYDROLOGIC-SALINITY FLOW SYSTEM WITHIN THE UPPER COLORADO RIVER BASIN,

5. Report Date

6.

7. Author(s)
Hyatt, M Leon, ~~et al~~ Riley, J. Paul, McKee, M. Lynn, Israelson, Engnene K.

8. Performing Organization Report No.

9. Organization
Utah State University, Logan, Utah Water Research Laboratory.

10. Project No. EPA Program 16090 DVU 07/70

11. Contract/Grant No.

12. Sponsoring Organization

13. Type of Report and Period Covered

15. Supplementary Notes
Report PRWG 54-1, July, 1970, 255p, 109 fig, 31 tab, 85 ref, 9 append

16. Abstract

Changes in the hydrologic equilibrium of a river basin resulting from resource development also produce changes in the quality pattern. Since the burden of quality maintenance must be shared by users (just as are quantities) predictions are needed for quality changes which might result from contemplated development at any specified location within the river system. This study reports the development of a computer simulation model of the water and salt flow systems within the Upper Colorado River basin.

Because of the close relationship between the hydrologic and salinity flow systems, an understanding of the hydrologic system is essential to successful management of the salinity system. In this study development of a hydrologic model is based on water budgeting or accounting procedures, in which available data on historical water flows, municipal and industrial uses, and the demands of agriculture are used. The salinity dimension is then added, and the joint hydro-salinity model is verified (calibrated and tested) by comparing computed and observed output values.

The utility of the model is demonstrated by applying it to a particular subbasin of the San Juan River and predicting the effects on downstream water quantity and quality of developing a large irrigation project within the area.

17a. Descriptors Water quality, *Colorado River basin, *Salinity, *Model studies, *Computer models, *Irrigation efficiency, *River basins, Water demands, Water utilization, *Forecasting, Flow, Utah

17b. Identifiers San Juan River basin,

17c. COWRR Field & Group 07C, 02E, 05G

18. Availability Available from the National Technical Information Service as PB 203 674, $3.00 in paper copy, $0.95 in microfiche

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

Abstractor

Institution

WRSIC 102 (REV. JUNE 1971)

GPO 913.261

CHAPTER I
INTRODUCTION

The current rapid growth of demands upon water supplies throughout the United States is imposing an increasingly heavy load upon this limited resource from both a quantity and a quality standpoint. In areas where water supplies are short, such as the Upper Colorado River basin, demands are met both by importation and by improved management of existing supplies. Unfortunately, increased utilization of the existing supplies through use and reuse of water for irrigation and industry concentrates and adds non-degradable substances which produce a degeneration of water quality. For example, the natural inorganic salts leached by percolating waters from the rocks and minerals of the soils within a watershed are concentrated by the consumptive use of irrigation water. The problem is further aggrevated by the leaching effects of the excess irrigation waters as they percolate through the usually fertilized soils of irrigated areas. In addition, concentrations of pesticides, herbicides, insecticides, and other persistent compounds are generally increased through each agricultural use cycle. Municipal and industrial uses also degrade water quality through the addition of both organic and inorganic substances to the supply. Further, increased water temperature, or thermal pollution, often results from municipal and industrial use.

Thus, in every hydrologic system each upstream use has some effects on the quantity, quality, and timing of flow occurring at downstream points. A key question, therefore, associated with any proposed upstream change or management alternative is--what are the likely downstream effects? Realistic answers to this question can lead to increased use and better efficiency of available water resources within the basin.

As already indicated, increased water salinity, or total dissolved solids, results from various uses, such as irrigation, but the extent to which each use contributes to the salinity load in a particular situation is a controversial question. The promotion of complementary uses and the reduction of controversy and competition for the existing resource is a necessary aim of good management. Proper evaluation of the downstream consequences resulting from upstream changes is difficult because of the complex interrelation and variable nature of the hydrologic and salinity flow systems. However, many of the factors affecting these flow systems are subject to manipulation and regulation, and through proper management criteria, optimum use of the water resources of the basin can be achieved.

This report considers the hydrology and the quality systems within the basin of the Upper Colorado River. In order to limit the scope of the study, the only water quality parameter or criterion considered is that of total dissolved solids, or salinity. In the irrigated and somewhat sparsely settled areas of the western United States, the total dissolved solids content of water has been the parameter most generally responsible for limiting water reuse. In varying degrees, agricultural crops are sensitive to water salinity levels. In some cases high salinity levels render the water objectionable or unsuitable for reuse not only by agriculture but also by industries and municipalities. Thus, because of the dominating role of the agricultural use of water within the drainage area of the Upper Colorado River, salinity is a highly critical quality criterion within this basin.

The water resources of the Upper Colorado River basin are profoundly influenced by both the geology and management practices of man. In the mountainous areas where most of the water supply originates, there is a continuous interchange between surface and groundwaters. In this process, the rocks react with the water and give to it chemical constituents which are characteristic of the geology ~~of~~ each particular area. As a result, wide geographic variations occur in water salinity levels throughout the basin.

The waters in the Upper Colorado River basin are used by man for a variety of purposes, including domestic, industrial, and municipal, irrigation, production of hydroelectric power, preservation of fish and wildlife, and recreation. Water is also exported for use in adjoining basins. The most important of these uses, and that which has the greatest influence of water salinity levels, is irrigation. Summertime flows in the lower reaches of many tributaries are composed largely of return water from irrigated areas. These return flows often have a profound effect on the concentration of salts dissolved within the streams. Thus, because the economy of the Upper Colorado River basin is strongly oriented towards agriculture, the continued expansion of irrigation use, short of direct separation of the water from its dissolved solids or the importation of additional supplies, depends upon the development of increasingly sophisticated management schemes for available water supplies within the basin.

The development of a specific and quantitative description of a hydrologic system and its associated salinity dimension is a difficult problem because of the complex and variable nature of the many different processes which occur simultaneously within the total system. The problem is, therefore, to describe in mathematical terms the various processes which occur within the hydro-salinity system and to develop a realistic approach for combining these relationships into models which faithfully describe the system. Such models will allow easy and quick examination of the various parameters and output functions as they are affected by planning and management changes within the real-world basin being simulated.

With the advent in recent years of the modern high-speed electronic computers, mathematical simulation of various kinds of systems has become feasible. The simulation technique provides answers to questions which could not be solved by traditional analytical methods. The modern electronic computer (both analog and digital) has undergone intensive development in the past few years and is now capable of providing the necessary speed and flexibility required to solve the complicated and involved problems encountered in the simulation process.

Computer simulation to date has extensively utilized the digital computer. Such studies include the hydrologic model of Crawford and Linsley (1962b) which considers the abstractive processes of interception, depression storage, infiltration, and evapotranspiration in predicting both surface and subsurface flows. Dawdy and O'Donnel (1965) have developed a similar digital computer model which contains mathematical descriptions of the various fundamental processes of a hydrologic system. Other examples are the various hydrologic models developed by Betson and Green (1968), Machmeier and Larson (1968), and Moore (1968) which use the digital computer for the simulation of watershed hydrology. With reference to the water quality dimension, Kalinin (1968) suggested the possible application of the digital computer to the dynamics of runoff and the transport of solids and dissolved matter.

Electronic analog computer modeling in the various areas of water research include a study by Shen (1965) in which he discusses the applicability of analog models for analyzing flood flows. Harder et al. (1960) working at the Hydraulic Laboratory of the University of California developed an analog model for the purpose of routing floods in a particular river system. In addition, an analog model has been developed for simulating flood conditions on the Kitakami River of Japan (Otoba et al., 1965). Electric analog models consisting primarily of resistance and capacitor networks have been widely applied to groundwater flow systems (Schicht, 1963; Skibitzke, 1960; Stallman, 1963; Walton and Prickett, 1963; and Anderson, 1968).

The analog computer also has been applied to research involving water quality parameters. Three studies are cited in which oxygen sag curves for river systems were simulated (Cohen and O'Connell, 1963; Falk, 1962; and Rennerfelt, 1964). Considering the water quality system in a broad sense, Odum (1960) developed some analog circuits for modeling the ecosystem.

Simulation of hydrologic systems with the aid of the electronic analog computer began at Utah State University in 1963 (Bagley et al., 1963). Initial simulation efforts were relatively simple with the primary objective being to develop a non-unique model with respect to geography in terms of the basic physical processes which occur in any hydrologic system, and to demonstrate the utility of the analog computer for model verification and sensitivity studies. Riley et al. (1966, 1967), encouraged by the results of the initial study, developed improved mathematical relations for describing the various hydrologic processes and the interconnecting links between those processes. Most recent efforts have involved interlinking the hydrologic system with other dimensions, such as economics (Packer et al., 1968) and water quality (Hyatt et al., 1968; and Dixon et al., 1970). Models have also been utilized for management studies involving entire river basins (Israelsen and Riley, 1968).

The study reported here involves the joint simulation of the hydrologic and salinity flow systems. Computer simulation of complex systems of this nature is broad in scope, and, as such, is highly dependent upon the previous findings of others. In particular, many of the modeling concepts and techniques used were based upon previous work in the simulation program at Utah State University.

The particular area modeled in this study is the Upper Colorado River basin; however, any physical river basin could have been selected inasmuch as the basic relationships and simulation techniques proposed are of a general nature. The Upper Colorado River basin was selected for the following reasons:

1. Although inadequacies exist in the intrasubbasin network, a reasonably good sampling network exists within the basin for both hydrologic and quality information.

2. Within the basin the water quality, and salinity in particular, is a problem of immediate concern. Presently, water supplies

in the Upper Basin are, in general, suitable for the various uses of man. However, it is estimated that the average concentration of dissolved solids in the Colorado River at Lee Ferry, Arizona, is increased from about 250 to 500 parts per million by domestic, industrial, and agricultural use of water within the Upper Basin. In many cases these increased salinity concentrations produce adverse effects upon water users within the Colorado River basin, especially in the Lower Basin, where at some locations the problem is already critical.

3. The basin incorporates quality problems which are both interstate and intrastate in scope, and thus are of local, regional, and national importance.

The Upper Colorado River basin is located in the western United States and lies within the states of Colorado, New Mexico, Utah, and Wyoming. The basin contains an area of approximately 110,000 square miles. Much information pertinent to this area is contained in two reports published by the U.S. Geological Survey (Iorns et al., 1964 and 1965). These two reports were utilized where possible in this study. Besides the main topographic and geologic features of the basin, the reports include data on evaporation, precipitation, streamflows, water quality, stream sediment loads, and the locations of many of the irrigated areas.

The techniques developed by this study can prove a valuable asset to managers who are faced with decisions regarding the utilization of available water resources. Thus, the study should provide some of the following benefits:

1. Illustrate the general nature of the hydro-salinity model as being applicable to any river basin.

2. Demonstrate the utility of an electronic analog computer for the development of a simulation model of the complex hydrologic and salinity flow systems of a river basin.

3. Indicate the advantage of the computer model for evaluating various alternative management possibilities for a water supply of a fixed quantity and quality.

4. Provide improved understanding of the operation of the hydro-salinity flow system, and thus indicate the relative magnitude of salinity contributions from various sources.

5. Indicate deficiencies in available water quality and quantity data.

6. Indicate areas where additional study is needed to improve the description of the hydrologic and salinity flow systems.

CHAPTER II
COMPUTER SIMULATION OF SYSTEMS

In spite of the progress which has been made in the management and control of our water resources, continued research and investigation is still necessary to ensure the most efficient use of these resources. Studies involving real time units and physical models often are not practical. The problem may be effectively approached by defining an analogous system for computer solution which circumvents such factors as danger, time limitations, expense, and inconvenience associated with testing the prototype system. The technique of computer simulation usually involves definition of the constraints and system processes in mathematical terms and of synthesizing these relationships on a computer into a dynamic model of the prototype. The model is then operated to test the relative importance of various processes within the prototype, and to yield output functions corresponding to given or assumed management alternatives.

Simulation Techniques

Simulation is a technique for investigating the behavior or response of a dynamic system subject to particular constraints and input functions. The process involves measurement or observation of model parameters and output functions when the model is subjected to conditions similar to those confronted by the prototype. Simulation can be performed by either physical or electronic models. Physical models are scaled reproductions of the prototype structure to which they bear physical resemblance. Historically these models have been dominant in the design of hydraulic structures such as dams, spillways, and flood control works.

Within the category of electronic models are the resistance-capacitor networks, or direct analogy models, and those utilizing the high-speed electronic computer. For many years direct analogy models, often referred to as network analyzers, have found a place in the investigation of various hydraulic and hydrologic phenomena. In this type of model each electrical component corresponds directly to a physical element in the prototype, thus creating a direct similarity between the system of the prototype and the electrical network, which is usually constructed of resistance and capacitance components. As discussed in Chapter I, the application of electronic computers to simulation is a relatively new technique. This procedure involves the use of a computer to synthesize a mathematical model of a prototype system. Thus, mathematics become the link between the computer model and the prototype. Time and space scales consistent with the requirements of the problem and data availability are readily selected. Computer simulation, therefore, allows the solution of nonlinear and dynamic models of highly complex systems. Modern electronic computers (both digital and analog) with their extreme speed and flexibility facilitate easier simulation of entire systems including their complexities and various constraints.

The basic requirement of a computer approach to the simulation of a physical system is that the important processes and relationships within the system be modeled on a continuous basis. This requirement is met by subjecting a preliminary model, founded upon basic relationships and data, to an evolutionary process of trial, feedback of information, and improvement until a satisfactory model is developed.

The advantages of computer simulation include an opportunity to evaluate proposed modifications at a minimum expense and effort; non-destructive testing of the system; no time loss or inconvenience in the prototype system while improvements or modifications to existing works are considered; and considerable insight into the physical relationships and properties of the system receiving consideration.

Utilization of Computers for Simulation

Intensive development programs have provided a rapid growth in computer capability, and have been a major factor underlying the current extensive application of computers to simulation problems. Traditionally electronic computers have been divided into two general classes, namely digital and analog. Recently, however, the hybrid computer has evolved from a combination of these two types of computing systems. Riley et al. (1969) provide a short treatise of the various aspects of these three major computer types, and this material is briefly summarized in the following paragraphs.

Preceding page blank

Digital computers

The modern general-purpose digital computer utilizes a sequential procedure to perform step-by-step operations at high speed and great accuracy on combinations of discrete or instructive data. This computer is a powerful tool in the processing of large quantities of data and in solving complex mathematical problems capable of being converted to numerous simple arithmetic operations. The ease with which a digital computer may be programmed and its ability to perform logical operations and precise arithmetic calculations at high speed make it a useful computing device.

Analog computers

Riley et al. (1969) describe an analog computer as a collection of operational electronic components which perform mathematical operations by addition, substraction, multiplication, generation of functions, and high speed integration. These processes are carried out through the interconnection of computer components on a program "patch panel." Hence, the formation of a single or series of differential equations, and other relationships, are programmed on a patch panel to describe the dynamic or time varying performance of a system. Input parametric quantities are usually established in the analog computer by the setting of potentiometer dials and output quantities may be plotted graphically for any point within the system.

The analog computer solves problems by behaving electronically in an analogous manner to the prototype. Since the analog computer is a parallel device (all computations proceed simultaneously), doubling of the problem size requires a two fold increase in the amount of analog equipment needed for the problem, but the solution time remains the same. On the other hand, the digital computer, which is a sequential machine, takes twice as long when the problem size is doubled.

Many of the processes which occur in nature are functions of time and they may be expressed as time dependent differential equations. The analog computer is particularly applicable to problems of this nature because it can integrate the problem variables on a continuous basis throughout the integration period instead of using numerical approximations. Occasionally, problems involving stochastic variables require differential equations to be solved repeatedly, each with slightly different parameters, coefficients, or functions. Because of its inherent characteristics, iterative problems of this nature readily can be undertaken on the analog computer. Simulation allows insight to the dynamics of a prototype system through continuous immediate graphical output and visualization of results which are the actual dynamic responses to any change in a specific phase of the program. Thus, the analog computer is useful both during the exploratory phases of development of component relationships and the formulation of a composite model of a prototype system.

Recently, digital computer programs have been developed to permit utilizing the digital computer as an analog computer wherein statements are submitted to the digital computer which define the intercommunication of "simulated" analog computer operational components. However, the sequential nature in which the digital computer must handle the data imposes a speed restriction, especially for simulation problems involving highly complex and non-linear systems.

Hybrid computers

Based on the preceding paragraphs, it appears that the most effective means of simulating complex systems is to employ both the analog and digital computation techniques. The system resulting from a linking of the digital and analog computers incorporates the capabilities of each type, and is referred to as a hybrid computer. The hybrid computer allows a high level of efficiency in computer simulation and combines high speed with dynamic accuracy. A computer of this type has been installed at the Utah Water Research Laboratory on the campus of Utah State University. However, throughout this simulation study the primary computational device used was an electronic analog computer.

Modeling Approach

The model proposed for simulation on the analog computer is a dynamic system consisting of three basic components, namely the medium or media acted upon, a set of constraints upon the system, and driving forces upon the system. For a hydrologic system, water becomes the medium of interest, the physical nature of the hydrologic basin forms the constraints, and the driving forces are supplied by solar energy, gravity, and capillary fields. In the salinity system, salts become the media acted upon and the constraints and driving forces are the same as for the hydrologic system except that gravity is the predominant driving force.

Since both the hydrologic and salinity flow systems are dynamic in nature, the various functions and operations can be related through the concepts of continuity of mass and momentum. Continuity of momentum is important only if high velocities are encountered, so its effects may be considered as essentially negligible. Hence, both the hydrologic and salinity flow systems utilize the principle of continuity of mass to interrelate or link the various processes within the system. Expressed in equation form, the continuity of mass principle states:

$$\text{Input} = \text{Output} \pm \text{Change in storage} \quad \ldots\ldots\ldots\ldots (2.1)$$

The hydrologic balance is obtained through application of this equation to the system to achieve an accounting of the physical hydrologic quantities at various points within the basin. Utilizing this concept, water is translated or routed through the system in the proper relationship to both space and time. In the salinity flow system salt moves by the dilution and mixing of flows. Thus, the salinity system is superimposed upon that of the hydrology, and the mass rate of salt movement is reflected by salinity concentrations in the water flow. The concentration of salts (TDS) at a given water discharge indicates the mass rate of salt flow. The hydrologic and salinity flow systems are thus related by the salinity concentration at a given rate of water flow. The rate of salt input to a system is estimated from the salinity concentration levels of all hydrologic flow inputs. Considering storage changes and influences produced by water uses within the system, the mass balance concept provides an estimate of the resultant TDS concentration at the outflow of the system. Utilizing time increments of one month, assumed sufficiently long for thorough mixing, the mass balance of solids is simulated and evaluated by the analog computer. When model verification is completed for a particular system, the input and individual model parameters are varied and the effects of these changes are observed at any point within the system.

It is apparent from the preceding discussion that the concept of balance is utilized for translating the input functions through the abstractive and storage processes of the system to produce various output values. As the water and salt flow pass through the system, storage changes occur on the land, in the soil moisture and groundwater zones, and in stream channels. Such changes occur rapidly at surface locations and more slowly in the subsurface zones. Because these changes occur in both time and space, consideration must be given to these dimensions in formulating a model of the system.

Time and Spatial Considerations

Any suitable time increment or space unit can be utilized in a simulation model of a water resource system. The space unit might consist of an entire river basin, a subbasin, a particular zone, or even an infinitesimal area. Time increments might also vary from years to seconds. The size selected for both the time and space increment essentially depends upon the answer sought or the problem to be solved.

The complexity of a model designed to represent a flow system depends upon the time and spatial increments utilized in the model. Hence, when large increments are applied, the scale magnitude is such that the effects of phenomena which change over relatively small increments of time and space (microscopic aspects) are insignificant. As the time and space increments decrease, improved definition of the various processes within the system is required and the model complexity consequently increases. The ultimate in modeling would utilize continuous time elements and infinitesimal space increments portrayed and connected as in the prototype system. From a practical viewpoint, the limitations of this approach are obvious. Data limitations and model complexity require that finite increments of time and space be used. For example, data such as temperature and precipitation readings, canal diversions, and groundwater pumpage, are usually available only as point measurements in both space and time. Integration of these kinds of data in both of these dimensions is accomplished by the method of finite increments.

A major objective of this study was to simulate, by means of an analog computer, the hydrologic and salinity flow systems within a river basin. Because of the scope of the problem and data limitations a model based on large increments of time and space (macroscopic) was adopted. When warranted, a macroscopic model of this nature can be refined by reducing the time and spatial increments of the model. For example, considerable interest is now evidenced in the phenomenon occurring within the soil profile relating to the precipitation and exchange reactions of various ions. These reactions are functions of the composition and concentration of salt in the irrigation water, soil properties, irrigation practices and other related characteristics. Adequate description and simulation of the reactions within the soil require a small spatial increment. Similarly, precipitation interception rates and changing snowpack temperatures are processes which can be included only in models based on a small time increment.

The suggested approach to the development of a model of the hydrologic and salinity flow systems is to consider initially a macroscopic scale. The area is subdivided into relatively large, yet meaningful components, and within each of these the more fundamental and basic processes of the system are described. Once a model of this nature is verified, definition can be improved by reducing the magnitudes of the control volumes and time increments. The improved model is then capable of solving the same basic relationships as its predecessor as well as many additional problems which require detailed description. Thus, the simulation technique proceeds in logical steps to improved system understanding and definition.

Based upon the requirements of this study, form and availability of data, and the computer capacity, the following spatial and time increments were adopted:

1. Spatial increments consisting of a large drainage area or subbasin, of which only the valley bottom or agricultural area is considered. The entire Upper Colorado River basin was subdivided into 40 subbasins, and these are described at a later point in this report.

2. Time increments of one month.

For some processes significant changes occur within one month whereas for longer time periods changes in these processes are often negligible. For example, on an annual basis the effect of storage changes within a hydrologic system are often insignificant, yet on a monthly basis these changes may be appreciable and require consideration in the model. Throughout this report the subscript r applied to any parameter is used to designate the variation of the parameter with respect to time, whether it be an instantaneous rate or an average value occurring over a finite time interval, such as a day or a month.

The hydrologic and salinity model developed under this project includes only the various processes and routing phenomena which occur in the valley bottom of each subbasin. It is these areas that are most subject to the management activities of man, and exclusion of the surrounding watersheds reduces the size of the model. However, in modeling the valley bottoms the surrounding watersheds were considered from the viewpoint of their surface and subsurface contributions to the valley floors. The various ramifications of this approach are discussed at a later point in the text, and it is sufficient to state at this point that the watersheds were not neglected in this simulation study.

CHAPTER III
THE HYDROLOGIC MODEL

The hydrologic model utilized in this study is a modified version of that developed in earlier studies which demonstrated the applicability of an analog computer for the simulation of a complete watershed unit (Riley et al., 1966 and 1967). The model is macroscopic in scale, utilizing monthly time increments and large increments of space. As previously indicated, further simplification was achieved by including only the valley bottom lands of each subbasin.

The basis of the hydrologic model is a fundamental and logical mathematical representation of the various hydrologic processes and routing functions. These physical processes are not specific to any particular geography but rather are applicable to any hydrologic unit, including all of the subbasins located within the Upper Colorado River basin. Experimental and analytical results were used whenever possible to assist in testing and establishing some of the mathematical relationships included within the model. Under a model verification procedure, equation constants are established which calibrate or fit the model for a particular drainage area. Average values of hydrologic quantities needed for model verification were estimated in one of three ways: (1) from available data, (2) by statistical correlation techniques, and (3) through verification of the model.

A flow diagram of the hydrologic system is shown by Figure 3.1. As this flow chart indicates, the total input to a subbasin is the combination of surface and subsurface inflows obtained by summing river and tributary inflows, precipitation, and imports from other basins. Depletions from the subbasin occur through evapotranspiration, municipal and industrial consumption, and exports. The residual quantity is a combination of surface and subsurface outflow of water from the area. Subsurface flows may undergo various time delays as they move through the system. Each parameter and process depicted by Figure 3.1 is discussed in some detail in the following sections.

Additional understanding may be gained throughout the report from the fact that the subscripts i and o generally refer to inflowing and outflowing quantities, s and g usually refer to surface and subsurface flows, m and u generally refer to measured and unmeasured flow rates, and r is any flow rate.

River and Tributary Inflows

The basic inflow or input of water into any hydrologic system originates as a form of precipitation. However, for simulation models of valley floor areas, direct precipitation input to the system is greatly overshadowed by river and tributary inflows.

Streamflow is defined as that portion of the precipitation which appears in streams and rivers as the net or residual flow collected from all or a portion of a watershed. When unaffected by the activities of man such runoff is referred to as "natural or virgin" flow. Except in headwater reaches, few streams in the Upper Colorado River basin now carry natural flows. Artificial diversions and regulatory action in lakes and reservoirs affect the regimes of many streams within the basin.

Runoff from a watershed may consist of essentially three components, namely surface runoff, subsurface runoff or interflow, and groundwater runoff. Hence, when all flow components unite in a stream channel the runoff is thereafter considered to be streamflow. In general, the discharge of streams within the Upper Colorado River basin increases in a downstream direction, thus reflecting the influence of the progressively increasing drainage area. In this report the words runoff and flow are considered to have synonomous meanings and are used interchangeably.

Surface inflow

The surface water inflow component consists of that flow traveling over the ground surface and through channels to enter a stream. At the stream, surface runoff usually combines with other flow components to form the total runoff hydrograph. Within the runoff cycle (Chow, 1964), surface runoff begins to occur when the capacities of vegetative interception, infiltration, and surface retention are reached. Continued precipitation beyond this point serves as a source for surface runoff. The rate and volume of surface runoff depends upon climatic factors, such as form, duration, and intensity of

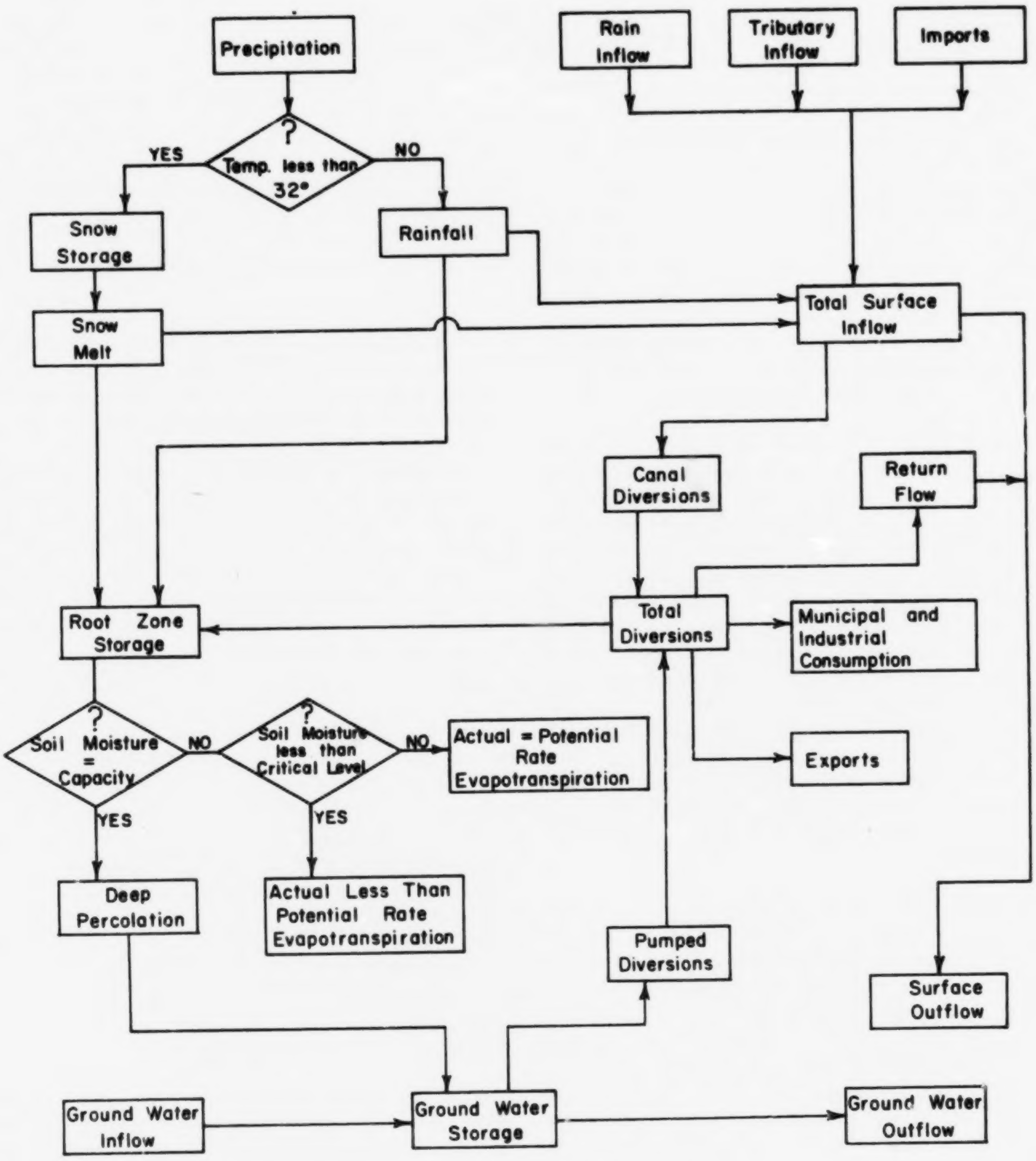

Precipitation
Rain Inflow
Tributary Inflow
Imports
? Temp. less than 32°
YES
NO
Snow Storage
Rainfall
Total Surface Inflow
Snow Melt
Canal Diversions
Return Flow
Root Zone Storage
Total Diversions
Municipal and Industrial Consumption
? Soil Moisture = Capacity
NO
? Soil Moisture less than Critical Level
NO
Actual = Potential Rate Evapotranspiration
Exports
YES
YES
Deep Percolation
Actual Less Than Potential Rate Evapotranspiration
Pumped Diversions
Surface Outflow
Ground Water Inflow
Ground Water Storage
Ground Water Outflow

Figure 3.1. Flow diagram for hydrologic flow system.

precipitation; the abstractive functions, including interception, evaporation, infiltration, and transpiration; and various watershed physiographic factors, such as drainage density, degree of slope, and other physical characteristics. Hence, small basins have different runoff characteristics than do large watersheds, and the characteristics peculiar to each basin must be evaluated on an individual basis.

For each subbasin in the Upper Colorado River basin, a limiting rate of surface runoff exists for any particular time period. Surface runoff is assumed to occur when the threshold or limiting rate of surface water supply, consisting of snowmelt, rainfall, canal diversions, or any combination of these, is exceeded.

This concept of surface runoff is particularly important when precipitation is considered as the initial water input to the watershed. Riley and Chadwick (1967) indicate that for particular conditions there exists a limiting or threshold rate of surface supply, R_{tr}, at which surface runoff, S_{wr} begins to occur. This relationship can be written:

$$S_{wr} = W_{gr} - R_{tr} , (S_{wr} \geq 0) \quad . . . (3.1)$$

in which

S_{wr} = rate of surface runoff during a particular time

W_{gr} = rate at which water is available at the soil surface

R_{tr} = limiting or threshold rate of surface water supply at which surface runoff begins to occur

When considered for a model time increment of one month, an average value of the threshold surface runoff rate, R_{tr}, is probabilistic in nature depending essentially upon soil surface conditions, soil moisture, storm characteristics, and rate of available water, W_{gr}.

In this study only the valley bottom lands are included within the model, and with the major inflow to the system concentrated in stream channels it is assumed that no surface runoff from precipitation occurs from these relatively flat areas. Under this assumption, the rate at which precipitation is available at the soil surface at no time exceeds the threshold rate for surface runoff to occur. Thus,

$$S_{wr} = 0 , (W_{gr} \leq R_{tr}) \quad . . . . (3.2)$$

It is emphasized that the model does provide for surface runoff from agricultural lands due to irrigation application rates which exceed soil infiltration rates. This runoff quantity constitutes a portion of the irrigation return flow.

Surface runoff from the surrounding watershed areas is mainly concentrated in stream channels, and therefore enters the model (valley bottom) as tributary flow. That part of this inflow rate which is measured or gaged is designated as Q_{is} (m).

Unmeasured surface inflows to the model are estimated by a correlation technique which considers three hydrologic parameters, namely a gaged tributary inflow rate, precipitation rate, and snowmelt rate. Thus, in functional form:

$$Q_{is}(u) = \int [q_{is}(m) , P_r , W_{sr}] \quad . . . . (3.3)$$

in which

Q_{is} (u) estimated rate of unmeasured surface inflow

q_{is} (m) measured rate of surface inflow from a particular tributary area

P_r = gaged precipitation rate in the form of rain on the valley floor

W_{sr} = estimated snowmelt rate in terms of water equivalent.

If empirical correlation factors are included in the preceding equation, the expression becomes:

$$Q_{is}(u) = k_u q_{is}(m) + k_a P_r + k_b W_{sr} \quad . . . . (3.4)$$

in which k_u, k_a, and k_b are correlation factors relating ungaged surface inflow rate to, respectively, a gaged surface inflow rate, precipitation rate, and snowmelt rate. Each of these factors is established through the model verification process for a particular subbasin.

With reference to the measured tributary inflow rate, q_{is} (m), used in Equation 3.4, this quantity might refer to either the total measured tributary inflow or a specific stream within the area. The main selection criterion for the gaged area is that the watershed exhibit the same general runoff characteristics as that of the ungaged surface inflow.

The second independent term in Equation 3.4 refers to the rates of precipitation occurring on the valley floor in the form of rain. Because it is assumed that the influence of snow upon the surface runoff is restricted to the melt period, only rainfall is considered in this term of the equation. Generally, a direct plot of rainfall against runoff for individual storms yields a low correlation because of the variable nature of the factors affecting runoff (Chow, 1964). However, when mean monthly values of precipitation and runoff are considered many of the transient processes are smoothed and a reasonably good correlation of runoff with precipitation is often achieved.

The third independent term of Equation 3.4 considers the influence of snowmelt upon surface runoff. Snowmelt rates on the valley floor are predicted in the model by Equation 3.9. This process is discussed in further detail later in this chapter.

The total surface inflow rate to the model (valley floor) is estimated by summing the measured rate and estimated ungaged rate from Equation 3.4. Thus,

$$Q_{is} = Q_{is}(m) + Q_{is}(u) \quad . \; . \; . \quad (3.5)$$

in which Q_{is} refers to the total surface inflow rate, and the two independent quantities are as previously defined.

Subsurface inflow

Subsurface runoff or interflow is defined as the lateral movement of moisture through the plant root zone. The process is discussed in further detail at a later point in this chapter. Interflow rate, N_r, is not treated as a separate identity in the hydrologic model of the valley bottoms, but is considered as being a part of the surface runoff from irrigation. In most cases, small interflow rates are encountered in flat lands. Furthermore, for a model time increment of one month, interflow usually produces an insufficient delay time to enable this quantity to be distinguished from surface runoff.

Groundwater inflow

Groundwater or subsurface inflow refers to those waters which enter the model area or valley floor beneath the ground surface. A major source of groundwater in the subbasins of the Upper Colorado River is recharge through coarse intermontane alluvium located at the outlets of many tributary streams to the valley floors. Much of this water is subsequently discharged as effluent flow into the main channel of the valley, and thus provides a "base flow" for the stream. Discharge from the groundwater basin of the valley floor also occurs by way of spring flows, pumped waters, and consumptive use by phreatophytes.

Essentially, all groundwater is constantly in motion though velocities may range from several feet per day to only a few inches per year. This groundwater movement is basically confined to permeable geologic formations called aquifers which serve as transmission conduits. Movement and volume of groundwater runoff may be calculated through application of Darcy's Law, providing adequate data are available. However, subsurface data are sparse within the Upper Colorado River basin. Time and spatial distribution of groundwater flows were estimated by an empirical approach through the model verification procedure in this study. For the steep watersheds near the headwaters of major drainage divisions, groundwater inflows to the valley floors were usually sufficiently small to be neglected. As the study proceeded downstream to lower subbasins, it generally became apparent through the time distribution of the water inputs to the model in relation to the recorded outflow that groundwater inflow rates were appreciable. Correlation procedures and transport delays were then used to estimate and simulate groundwater movement into the subbasin. In these cases, groundwater inflow rates were estimated by correlation with either the total surface inflow into the subbasin or a representative tributary stream. This water was then distributed with time through use of long transport delay networks on the computer. The required delay setting of these networks was established during the model verification process. Hence, the rate of groundwater inflow was described as follows:

$$Q_{ig}(u) = k_c q_{is} \quad . \; . \; . \; . \quad (3.6)$$

in which

$Q_{ig}(u)$ = rate of total unmeasured inflow to the groundwater system
k_g = coefficient relating the rate of unmeasured groundwater inflow to a measured surface runoff rate
q_{is} = rate of surface runoff (either total measured tributary inflow or measured inflow from a representative tributary)

For several subbasins a subsurface outflow, as groundwater movement under the outflow gage in the stream bed alluvium, was determined by the model verification process. The time and spatial distribution of this outflow formed a component of the groundwater inflow or input to the adjacent downstream subbasin.

Total inflow

Total inflow rate to the valley bottoms (model area) consists of the summation of the surface, subsurface, and groundwater flow rates. The surface inflows, $Q_{is}(m)$, for the most part have already been summed and are concentrated in stream channels as they enter the valley floor or agricultural areas. Surface inflow rates are available from surface water records published by the U.S. Geological Survey (1954, and 1961-1967). These records were utilized wherever possible and discontinued records were extended by statistical correlations where required to obtain additional estimated values.

The remaining two components of total inflow, namely ungaged surface inflow and groundwater inflow, are estimated from Equations 3.4 and 3.6 respectively. Therefore, the total inflow to a given subbasin within the Upper Colorado River basin is given by the following expression:

$$Q_i = Q_{is} + Q_{ig} \quad . \; . \; . \; . \; . \quad (3.7)$$

in which the terms Q_{is} and Q_{ig} are given by Equations 3.5 and 3.6 respectively.

Precipitation

The ultimate source of water input to any hydrologic unit is precipitation in one form or another. Precipitation is considered to be any moisture which emanates from the atmosphere and falls to the earth.

For many simulation studies of river basins at Utah State University (Riley and Chadwick, 1967; and Riley, Bagley, Chadwick, and Israelsen, 1967) the primary water inflow to the system is precipitation on the watershed. However, in this study where the valley floor is the modeled area, direct precipitation input to the model is generally overshadowed by the magnitudes of the river and tributary stream inflows. Precipitation then becomes important to the system primarily as it affects the evapotranspiration process and as a correlation parameter for estimating a portion of the ungaged surface inflow.

Average precipitation

Precipitation input to the hydrologic system varies with respect to both time and space and it is therefore necessary to convert point measurements from climatological stations into an integrated or averaged monthly value over a finite area. Common spatial integration techniques include the Thiessen weighting procedures and the isograph method (Linsley, Kohler, and Paulhus, 1958). These techniques were used in part to provide estimates of the monthly precipitation values for a given subbasin as a function of time. The procedure is described in more detail in Chapter VI.

Some precipitation data are available for all subbasins adopted in this study. Missing values of monthly precipitation were estimated by establishing a correlation between adjacent stations within a subbasin. Thus,

$$P_{ix} = k_j P_{iy} \quad \ldots\ldots \quad (3.8)$$

in which

P_{ix} = the estimated precipitation in inches of water for a particular station x and for a particular month, i

P_{iy} = the measured precipitation for the same month from another station in the subbasin or a station located in an adjacent subbasin

k_j = the correlation constant relating stations x and y for a particular period, j

The length of period j depends upon the available information and the time scale adopted for the model.

In some instances precipitation data were not available for extensive areas within a subbasin. In these cases average precipitation lapse rates were developed between the ungaged area and an area surrounding a local climatological station at which precipitation data were available. The lapse rates were developed from isohyetal charts covering the states of Utah and Colorado (U.S. Weather Bureau, 1963). Since these charts indicate lines of equal average precipitation for two periods, May to September and October to April, lapse rates were determined for each period.

Forms of precipitation

Although there are several forms of precipitation, only two forms, rain and snow, are considered in this study. Air temperature is used as the criterion for establishing the occurrence of these two forms. This criterion is not an ideal index for determining the form of precipitation since no one temperature exists below which it always snows and above which it always rains. However, the surface air temperature appears to be the most suitable single index of precipitation form now available.

Based on investigations by the U.S. Army (1956) at a surface air temperature of 35 F there is a 50 percent chance that precipitation will be as snow, whereas at 32 F the probability is 95 percent of precipitation falling as snow. The surface air temperature value selected in this study as a reasonable criterion for determining precipitation form was 32 F. Above this temperature it was assumed to rain, and at this temperature or less it was assumed to snow.

Precipitation abstractions

A part of the precipitation falling on an area is stored on the vegetative cover. Because most of this water later returns to the atmosphere through the evaporation process, vegetative interception is regarded as a loss. Interception losses which occur over a long time period, such as a month, are generally expressed as a fraction of the total precipitation for that period (U.S. Army, 1956). That part of the precipitation which reaches the ground, namely the difference between the total precipitation and the interception losses, is generally labeled as "effective precipitation" for the area.

The magnitude of the interception loss is basically a function of the type and density of the vegetative cover within the area. Since the model of this study includes only the valley floors, which are essentially flat, agriculturally oriented areas, interception losses are neglected; and all precipitation is assumed to be effective.

Some of the precipitation which reaches the ground is retained in depression storage. This form of storage includes puddles and other depressions in the soil surface. Water leaves depression storage through either direct evaporation or as infiltration into the soil. Since this model involves large time increments of a month, abstractions to depression storage need not be treated separately but are assumed to be a part of the total evapotranspiration loss from the area.

Temperature

Air temperature is an important parameter in a hydrologic system because it can be utilized as a criterion for establishing the form of precipitation, and as an index of the energy available for the snowmelt and evapotranspiration processes. Temperature varies according to both time and space. To obtain average temperature values for the valley floor, or a portion thereof, within a particular subbasin requires that point measurements be utilized for estimating an effective or average temperature value for an area. One approach to this problem of spatial integration is to construct isothermal lines for particular time periods and to relate these to selected index stations (Riley and Chadwick, 1967). However, in this study average temperatures for a particular area and a given time period (one month) are estimated by a weighting process based on the distribution of the agriculture lands in relationship to the climatological gaging stations. This procedure is described in detail in Chapter VI.

For subbasins or watersheds in which temperature data are lacking, records from other stations in the same drainage basin are "lapsed" to the mean elevation of the agricultural lands of the subbasin under consideration. Whenever possible, average monthly lapse rates for a particular location were established from past records (U.S. Weather Bureau, 1950-1966) in conjunction with temperature records from an index station. The computed average monthly temperature lapse rates varied from the theoretical value of -3.6 F, but for all subbasins within the Upper Colorado River basin the calculated values were within the range of -2.8 to -4.5 F per 1000 feet elevation increase. In cases where insufficient data were available to estimate the lapse rate, the average atmospheric adiabatic rate of approximately -3.6 F per 1000 feet elevation increase was applied (Linsley, Kohler, and Paulhus, 1958).

Snowmelt

Although rational formulas which include the various factors involved in the snowmelt process have been developed, data limitations often prohibit a strictly analytical approach to the process. Rational models include fundamental processes, such as those which relate to energy transfer, and requirements for input data are high. An additional restriction to the analytical approach for snowmelt computation is a large modeling time increment such as a month. Many of the short-term, transient phenomena which occur within a snowpack cannot be represented in a macroscopic model of this scale. An empirical relationship was, therefore, adopted for this study model.

Riley et al. (1966) proposed a relationship which states that the rate of melt is proportional to the available energy and the quantity of precipitation stored as snow. As a differential equation the relationship is written:

$$\frac{d[W_s(t)]}{dt} = - k_s \, (T_a - T_b) \, \frac{RI_s}{RI_h} \, W_s \, (t) \qquad \ldots\ldots\ldots\ldots (3.9)$$

in which the undefined terms are:

k_s = a constant
T_a = surface air temperature in degrees F
RI_s = the radiation index on a surface possessing a known degree and aspect of slope
RI_h = the radiation index for a horizontal surface at the same latitude as the particular watershed under study
W_s = snow storage in terms of water equivalent
T_b = assumed base temperature in degrees F at which melt begins to occur. In this study T_b was taken as being equal to 32 F.

Riley et al. (1966) report reasonable agreement between predicted snowmelt rates from Equation 3.9 and observed values. They used a value of k_s equal to 0.10 based on studies using data from several snow courses in the Rocky Mountain area where average snow depths are high. It has been found, however, that the value of k_s is somewhat inversely dependent upon snowpack depth. In other words, as the snow depth decreases pack melt rates increase for a given energy input. Thus, k_s is relatively larger for areas of shallow snowpack depth and relatively smaller for areas where depths tend to be large. Since this model was confined to the valley bottoms, the value of k_s was found to vary from 0.20 to 0.50 depending upon the latitude, elevation, and particular characteristics of each individual subbasin. The radiation index parameter allows adjustment to be made for variation of the total insolation with land surface slope and aspect. However, since only the valley floors are included in the modeling area it is assumed that the topographic surface of the area is essentially horizontal. This assumption simplifies Equation 3.9 in that RI_s becomes equal to RI_h and their ratio goes to unity.

The independent variables on the right side of Equation 3.9 can be expressed as either continuous functions of time or as step functions consisting of mean constant values for a given time increment. For this study a time increment was utilized and integration was performed in steps over each successive time period. Hence, the final value of $W_s(t)$ at the end of a particular time period became the initial value for the integration process over the following period. On this basis, and setting the ratio RI_s/RI_h equal to unity, the differential form of Equation 3.9 becomes:

$$\int_{W_s(0)}^{W_s(1)} \frac{dW_s}{W_s} = -k_s (T_a - 32) \int_0^1 dt \qquad \text{. . . . . (3.10)}$$

or

$$W_s(1) = W_s(0) \exp[-k_s(T_a - 32)] \qquad \text{. . . . . (3.11)}$$

Canal Diversions

Canal diversions profoundly affect the time and spatial distribution of water within an irrigated area. A portion of this diverted water is evaporated directly to the atmosphere, a secord part enters the soil profile through canal seepage and infiltration on the irrigated lands, and the remainder returns to the source as overland flow. Some of the water which enters the soil profile is lost through plant consumptive use. The remainder either percolates downward to the groundwater basin or is intercepted by drainage systems. Irrigation practices, therefore, alter both the distribution and the water quality characteristics of a hydrologic system. The irrigation efficiency factor used in this study includes both the conveyance and application efficiencies and is not the same as the usual concept of irrigation efficiency. Multiplying total diversions by the efficiency factor provides an estimate of that quantity of water which enters the soil through canal seepage and infiltration. The deep percolation losses associated with irrigation practices are discussed in a later section. The composite irrigation efficiency factor is given by the following expression:

$$Eff = 100 \frac{W_{dr}}{W_{tr}} \qquad \text{. . . . . (3.12)}$$

in which

Eff = water conveyance and application efficiency in percent

W_{dr} = rate at which diverted water enters the soil through seepage and infiltration

W_{tr} = total rate at which water is diverted from the stream or reservoir

Water diversion rates to the agriculture lands within each subbasin were obtained from records located in the offices of the State Engineers of the respective Upper Basin states.

As already indicated, a portion of the water diverted for irrigation returns to the streams as overland flow and interflow. Although the large time increment allows this water to be treated in the model as a single identity, it is important to distinguish between the two components. Overland flow (often termed tailwater) is surface return flow or runoff from the end of the field resulting from the application of water to the irrigated land at rates exceeding the infiltration capacity of the soil. Interflow is defined as that part of the soil water which does not enter the groundwater basin, but rather which moves largely in a lateral direction through the upper and more porous portion of the soil profile until it enters a surface or subsurface drainage channel. Both the overland flow and the interflow return to the stream channels in short distances and times consisting of usually only a few days. The distribution of canal diversions within the hydrologic system can now be expressed as follows:

$$OF_r = (1 - Eff/100)\, W_{tr} + N_r \qquad \text{. . (3.13)}$$

or

$$OF_r = (W_{tr} - W_{dr}) + N_r \qquad \text{. . . (3.14)}$$

in which

OF_r = total of overland flow (from irrigation applications at rates exceeding infiltration capacity rates) and interflow rates

N_r = interflow rate

All other quantities have been previously defined under Equation 3.12.

Evapotranspiration losses do not appear as such in Equations 3.13 and 3.14; however, these losses are considered because they are abstracted from the infiltration quantity represented by W_{dr} The evapotranspiration process will be further discussed in a subsequent section.

Available Soil Moisture

The usual definition of available soil moisture capacity is the difference between the field capacity and the wilting point of the soil. Water within this range is available for plant use, and is termed available soil moisture. The field capacity is defined as the soil moisture content after gravity drainage has occurred. Most of the gravity water drains rapidly from the soil thus affording plants little opportunity for its use. The wilting point represents the soil moisture content when plants are no longer able to abstract water in sufficient quantities to meet their needs, and permanent wilting occurs. Available soil moisture can be expressed in several units, but in this report it carries the unit of depth in inches of water per foot of soil depth.

Sources of available water

Basically, moisture in the soil is derived from infiltration, which is the passage of water through the soil surface into the soil profile. The water available for infiltration at the soil surface is derived from three sources: First, the effective precipitation, P_r, if this occurs in the form of rain; second, snowmelt, W_{sr}; as springtime temperatures rise to the point at which melting occurs, all snow cover on the land is assumed to melt and enter the soil mantle through the infiltration process; third, and in the case of irrigated crops, the most important source of available soil moisture is water which is diverted to the agriculture lands through the irrigation conveyance system. The rate at which water from this source enters the soil profile through canal seepage and infiltration has been previously designated as W_{dr}. Thus, the total water available for infiltration into the soil, W_{gr}, can be written as

$$W_{gr} = W_{dr} + P_r + W_{sr} \quad . . . (3.15)$$

in which all quantities are as previously defined.

Available soil moisture quantities

The maximum quantity of water in a soil available for use by plants is a function of the moisture holding capacity of the soil and the average rooting depth or extraction pattern of the plant.

The basic forces involved in the absorption of water by plants are osmotic, imbibitional, metabolic, and transpirational pull (Thorne and Peterson, 1954). These forces basically define the soil moisture tension or "pull" that must be exerted by the plant to remove water from the soil. Of these forces the principal one is the osmotic pressure created within plant root cells. Opposing these forces are those exerted on the moisture by the soil particles. The forces exerted by the plants vary with different plants, soils, and climates, but the average maximum force which plants can exert in obtaining sufficient water for growth is approximately 15 atmospheres of pressure. At field capacity where water is readily available for plant use, the average soil moisture tension is only about 0.1 atmosphere. However, the soil moisture tension or "pull" plants exert in their quest for water is in itself no indication of the amount of available water contained by the soil. The actual amount of water held by the soil at any given tension value is a function of the soil type. Typical values of available moisture capacity for various soil types are found in Table 3.1.

Table 3.1. **Approximate readily available soil moisture storage capacity in inches per foot of depth of soil (McCulloch, Keller, Sher[illegible]n, and Mueller, 1967).**

Soil Type	Moistures available to plants
Coarse sands	0.50"/foot
Fine sands	0.75"/foot
Loamy sands	1.00"/foot
Fine sandy loam	1.25"/1.50"/foot
Silt loam	1.75"/2.00"/foot
Silty clay loam	2.00"/foot
Clay loam	2.00"/2.25"/foot
Heavy clay	1.75"/foot

Determination of the soil depth effectively utilized by a plant is based on the average rooting depth or the average moisture extraction pattern. A typical extraction pattern for an irrigated crop in an arid region is shown by Figure 3.2. As this figure indicates, the typical agriculture crop extracts 70 percent of its moisture from the upper 50 percent of the soil penetrated by the plant roots. Average or typical rooting depths for various plants are reported by McCulloch et al. (1967). Illustrative depths include 4 to 6 feet for alfalfa, 4 feet for grains and corn, and 2 to 3 feet for pasture. From soil surveys and field investigations by various federal and state agencies, general soil types and crop distributions for each subbasin included in this study were obtained. Based on these distribution figures the percentage of each crop type within the agriculture area of each subbasin was computed, and a weighted (according to percentage of each crop) or average depth of the plant root zone was estimated. On the basis of this figure, the average available soil moisture capacity of the irrigated lands was estimated for each subbasin.

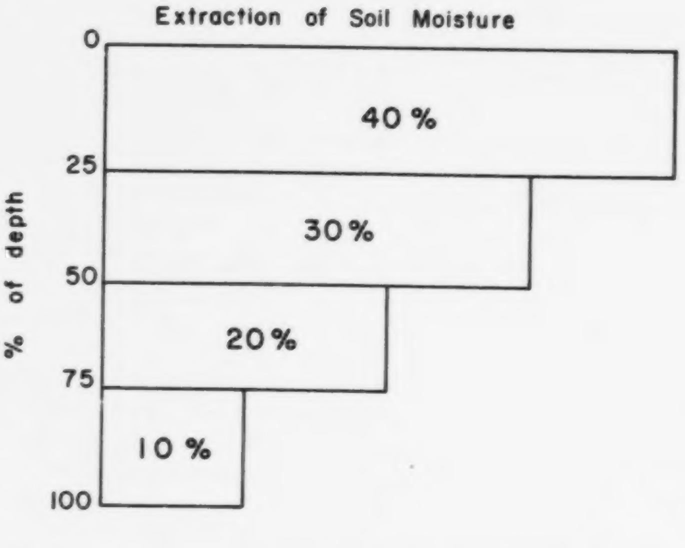


Figure 3.2. **Average extraction of soil moisture by plant roots between irrigations (Israelsen and Hansen, 1967).**

Under normal circumstances, additions to available soil moisture storage occur through the infiltration process, F_r. Abstractions or depletions from available soil moisture storage occur through evapotranspirational losses, ET_r, and deep percolation, G_r. The assumption is made, however, that deep percolation does not occur until the soil moisture capacity is reached. Thus, the soil moisture storage existing at any time, t, can be stated:

$$M_s(t) = (F_r - ET_r - G_r)\ dt \quad . . (3.16)$$

Each of the three terms on the right side of this equation is discussed in the following sections.

Infiltration

As already indicated, additions to available soil moisture occur through the process of infiltration, F_r. Factors which influence the infiltration rate include various soil properties and surface characteristics. A moisture gradient induced by the adhesive properties of the soil particles also influences infiltration rate.

In this study, the rate of infiltration into the soil is given by the following equations

$$F_r = W_{gr} \ , \ (W_{gr} \leq R_{tr}) \quad . . (3.17)$$

and

$$F_r = R_{tr} \ , \ (W_{gr} > R_{tr}) \quad . . (3.18)$$

for which all terms were previously defined. The quantity W_{gr} in Equation 3.17 is given by Equation 3.15.

Evapotranspiration

The second term on the right side of Equation 3.16 represents depletion from the soil moisture storage through the evapotranspiration process, ET_r. Consumptive use, or evapotranspiration, is the sum of all water used and lost by growing vegetation due to transpiration through plant foliage and evaporation from the plant and surrounding environment such as adjacent soil surfaces. Potential evapotranspiration is defined as that rate of consumptive use by actively growing plants which occurs under conditions of complete crop cover and a non-limiting soil moisture supply.

Methods of direct measurement of evapotranspiration rate

Consumptive use or actual evapotranspiration can be determined directly by several methods including tank and lysimeter experiments, field plot determinations, soil moisture studies, and water budget determinations for a particular basin area. The basis of each of these methods involves measuring the actual rate of water input to the area under study and subtracting from this value the measured outflow rate. The difference is assumed to represent the evapotranspiration rate by the plants during the time period considered. The study area can be treated as a unit for one or more crops, thus giving a composite figure for consumptive use. Alternatively, the area can be subdivided into small units from which evapotranspiration rates for individual crop species are estimated.

Regardless of the method used for measuring evapotranspiration rates, the problems encountered are numerous. Determining actual water input rates to the area, including precipitation, surface, and groundwater flows, as well as maintaining uniform water application rates, illustrate some of the difficulties encountered with these methods.

Methods for computing evapotranspiration rate

The evapotranspiration process depends upon many interrelated factors whose individual effects are difficult to determine. Included among these factors are type and density of crop, soil moisture supply, soil salinity, and climate. Climatological parameters usually considered to influence evapotranspiration rates are precipitation, temperature, daylight hours, solar radiation, humidity, wind velocity, cloud cover, and length of growing season. Numerous relationships have been developed for estimating the potential evapotranspiration rate, but these can be grouped into one of three general categories according to the approach used in their development, namely, vapor transfer, energy balance, and empirical relationship.

The vapor transfer process involves measurement of wind velocity, temperature, and vapor pressure differences in a layer of air near the evaporating ground or water surface. At present, lack of data limits general use of this method.

The energy balance process attempts to establish relationships describing the flow of energy responsible for evapotranspiration. This method includes a balance between net radiation and advective energy reaching the evaporating surface and energy required for evapotranspiration and heating the air and soil. Utilizing this concept, Penman (1948) developed a formula for estimating evapotranspiration rate. His results are good but tend to be low in regions of high temperature and low humidity. The approach is also handicapped by the laborious calculations required and a lack of data.

Numerous empirical relationships for estimating potential evapotranspiration rates have been developed. In general, these relationships are based on easily available climatological data, and thus have achieved broad acceptance. Some of the more familiar equations are discussed briefly in the following paragraphs.

The Lowry-Johnson formula (1942) describes the evapotranspiration process as a function of an effective heat factor and was developed to give an estimate of annual consumptive use. The formula is written:

$$U = 0.8 + 0.156\,F \quad \ldots\ldots (3.19)$$

in which

U = consumptive use in acre-feet per acre

F = effective heat in thousands of day-degree

Effective heat is the accumulation in day degrees of the maximum daily temperatures above 30 F.

Another well-known evapotranspiration formula was developed by Thornthwaite and Mather (1955) which is written as follows:

$$PET_n = 1.6\,L_n \frac{10T_n}{I}^{a}, \text{ for } T > -1^{\circ}C \quad \ldots\ldots\ldots\ldots (3.20)$$

in which

PET_n = potential consumptive use in inches for a given month

L_n = mean duration of sunlight during a month expressed in units of 30 days of 12 hours each

I = heat index = $\sum_{n=1}^{12} i_n$, $i_n = \left(\frac{T_n}{5}\right)^{1.514}$

a = $6.75\text{x}10^{7}I^{3} - 7.71\text{x}10^{5}I^{2} + 1.792\text{x}10^{-2}I + 0.49239$

An extensive effort to develop a universally applicable equation for estimating both evapotranspiration and evaporation rates was initiated by Christiansen (1966). Under the direction of Christiansen, Patel (1962) developed a formula designed to minimize personal judgment, possess broad geographic applicability, and utilize only generally available climatic data. However, the Patel formula yields results that are somewhat high (Christiansen, 1968). In a later study (Grassi, 1964) further refined the Patel formula to give improved results. The Grassi formula is written mathematically as:

$$E_t = 0.215\,C_r\,C_{Clc}\,C_t\,C_{td}\,C_{Crc}\,F \quad \ldots\ldots\ldots\ldots (3.21)$$

in which

E_t = evapotranspiration in inches per day

C_r = coefficient which is a function of radiation

C_{Clc} = coefficient describing cloud cover

C_t = coefficient for temperature

C_{td} = coefficient relating maximum to mean temperature for the period considered

C_{Crc} = coefficient describing stage of plant growth as a function of time

F = a crop factor

Values for each coefficient have been estimated from equations developed by multiple regression techniques. These values and those for the crop factor, F, have been published in tabular form (Christiansen, 1968). Grassi (1964) also proposed two additional formulas for estimating evapotranspiration rate. One of these expresses evapotranspiration rate as a function of measured incident radiation and various climatic factors. The second equation relates evapotranspiration rate to pan evaporation rate and several climatic factors.

When insufficient data exist for utilizing the fully expanded form of Equation 3.21, coefficients corresponding to the unavailable data can be assumed to equal either unity or any other reasonable value.

Although the formula proposed by Grassi (1964) appears to give good results, for two basic reasons it was not used in the model developed under this study. The first reason involves the considerable analog computer hardware requirements for programming an equation of this nature. The second reason is based upon the large amounts of meteorological data required by the Grassi equation. Primarily only precipitation and temperature data are available within the Upper Colorado River basin.

Perhaps one of the most universally applied evapotranspiration equations is that proposed by Blaney and Criddle (1950). This equation is written as follows:

$$u = kf \quad \ldots\ldots (3.22)$$

in which

u = monthly crop potential consumptive use in inches

k = a monthly coefficient which varies with type of crop and location

f = the monthly consumptive use factor and is given by the following equation:

$$f = \frac{tp}{100} \quad \ldots\ldots (3.23)$$

in which

t = mean monthly temperature in degrees F

p = monthly percentage of daylight hours of the year

A modification to the Blaney-Criddle formula was proposed by Phelan (1962) and others, wherein the monthly coefficient, k is subdivided into two parts, a crop coefficient, k_c, and a temperature coefficient, k_t.

The relationship describing k_t is an empirical one, depending upon only temperature and is expressed as:

$$k_t = (0.0173t - 0.314) \quad . . (3.24)$$

where t is the mean monthly temperature in degrees F. The crop coefficient, k_c, is basically a function of the physiology and stage of growth of the crop. Typical curves which indicate values of k_c throughout the growth cycle of particular crops are shown by Figures 3.3 and 3.4, which are for alfalfa and grass pasture respectively. Similar k_c curves are available for many agriculture crops (Soil Conservation Service, 1964).

Thus, the modified Blaney-Criddle equation for estimating potential evapotranspiration rates is written as follows:

$$ET_{cr} = k_c k_t \frac{T_a p}{100} \quad . . . . . (3.25)$$

Because of its simplicity, low data requirements (only surface air temperature is needed), and applicability to the irrigated areas of the Western U.S., Equation 3.25 was adopted for this study model. Since the time increment selected for use was one month, the variables on the right side of Equation 3.25 represent mean monthly values although these parameters could be expressed as continuous functions instead of the indicated step functions. Thus, Equation 3.25 estimates the mean potential evapotranspiration rate during each month.

The growing season was assumed to begin and end when the mean monthly air temperature reached a value of 32 F. Evapotranspiration losses from the agriculture area during the non-cropping season were estimated from Equation 3.25. For many crops it was necessary to extend the k_c curves (Figures 3.3 and 3.4) to include the non-growing season (West, 1959). Because the k_c curve for grass pasture (Figure 3.4) seems to represent a reasonable set of values for native vegetation (Riley et al., 1967), this curve was used as a guide in the development of a similar k_c curve for phreatophytes.

Effects of soil moisture on evapotranspiration

As was discussed earlier, as the moisture content of a soil is reduced by evapotranspiration, the moisture tension which plants must overcome to obtain sufficient water for growth is increased. Early studies by Hendrickson and Veihmeyer (1937) suggested that the growth and quality of various fruits were not affected by the soil moisture content unless it remained at the wilting point for several days. Since those early studies much research has been devoted to establishing the relative availability of water to plants over the entire moisture range from field capacity to wilting. It is now generally conceded that some reduction in the evapotranspiration rate occurs as the available quantity of water decreases in the plant root zone. Recent studies by the U.S. Salinity Laboratory in California (Gardner and Ehlig, 1963) indicate that transpiration occurs at the full potential rate through approximately the first one-third of the available soil moisture range, and that thereafter the actual evapotranspiration rate lags the potential rate due to higher soil moisture tensions. When this critical point in the available moisture range is reached, the plants begin to wilt because soil moisture becomes a limiting factor. Thereafter, an essentially linear relationship exists between available soil moisture quantity and actual transpiration rate. The actual evapotranspiration rate is expressed by Riley, Chadwick, and Bagley (1966) in accordance with the end conditions which accompany the two following equations:

$$ET_r = ET_{cr} , \; [M_{es} < M_s(t) \leq M_{cs}] \quad . . . . (3.26)$$

and

$$ET_r = ET_{cr} \frac{M_s(t)}{M_{es}} , \; (0 \leq M_s(t) \leq M_{es}) \quad . . . . (3.27)$$

in which

ET_r = actual evapotranspiration rate
ET_{cr} = potential evapotranspiration rate
M_{es} = limiting or threshold content of available water within the root zone below which the actual becomes less than the potential evapotranspiration rate
$M_s(t)$= quantity of water available for plant consumption which is stored in the root zone at any instant of time
M_{cs} = root zone storage capacity of water available to plants

Because they are differential with respect to time both Equations 3.26 and 3.27 are easily programmed on the analog computer. In the integrated form Equation 3.27 appears as:

$$M_s(2) = M_s(1) \exp \left[- \frac{ET_{cr}}{M_{es}} (t_2 - t_1) \right] \quad . . . . (3.28)$$

in which $M_s(1)$ and $M_s(2)$ are the soil moisture storage values at time t_1 and t_2 respectively. Hence, when conditions are such that the available soil moisture storage reduces the potential evapotranspiration rate, the actual consumptive use rate can be expressed by combining Equations 3.25 and 3.27 to read:

$$ET_r = \frac{M_s}{M_{es}} k_c k_t \frac{T_a p}{100} \quad . . . (3.29)$$

Equation 3.29 is programmed on the analog computer to estimate actual evapotranspiration rate. The equation reduces to Equation 3.25 when $M_s > M_{es}$ so that $ET_r = ET_{cr}$.

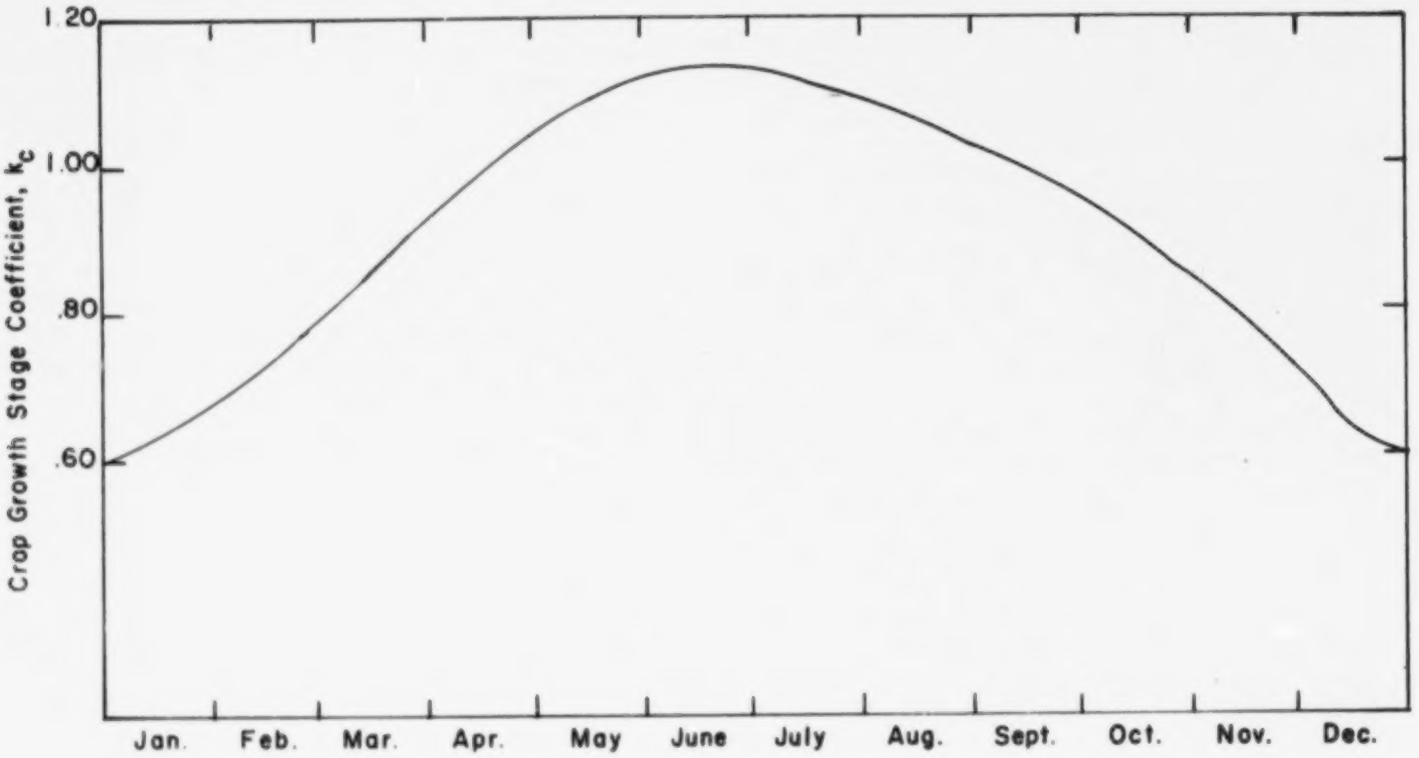


Figure 3.3. Crop growth stage coefficient curve for alfalfa.

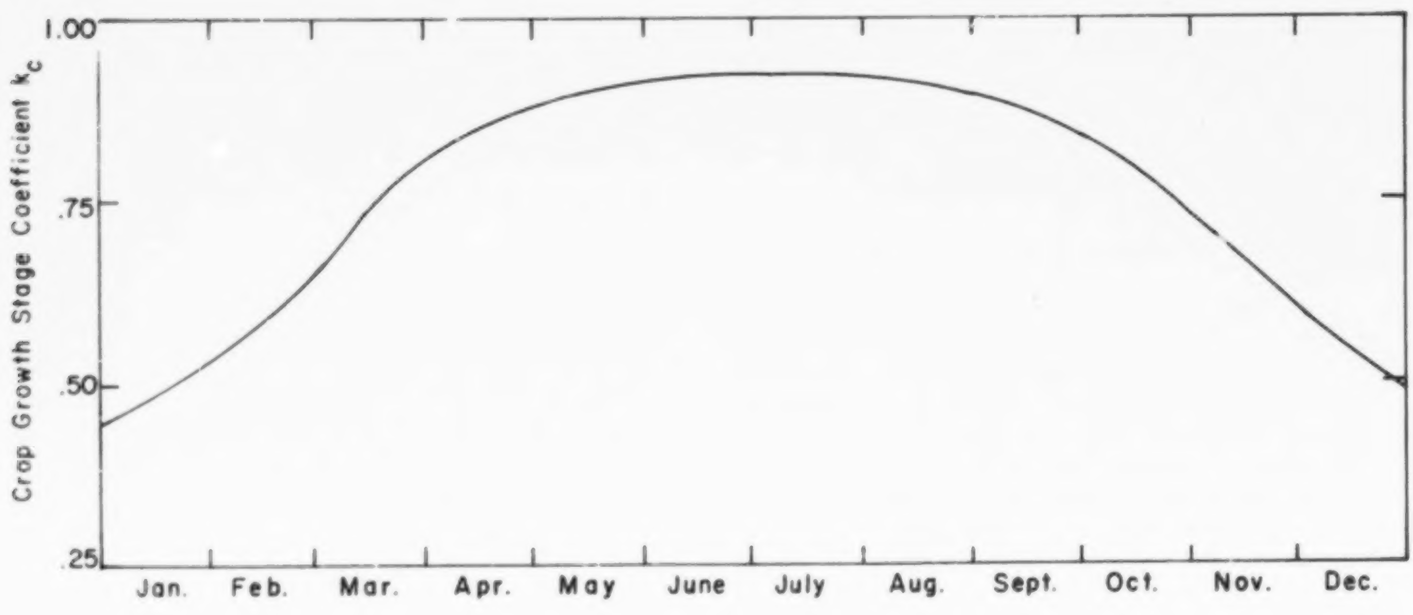


Figure 3.4. Crop growth stage coefficient curve for grass pasture.

Effects of slope and elevation on evapotranspiration

In that they affect the available energy supply, land slope (degree and aspect) and elevation influence the evapotranspiration process. Riley and Chadwick (1967) considered the effects of slope by introducing a radiation index parameter. These same authors also introduced an elevation correction into Equation 3.29. This adjustment is necessary for watershed studies since surface air temperature becomes a less reliable index of the available energy with increased elevation above the valley floor. However, because the model of this study was confined to the relatively flat valley floor areas, the effects of both slope and elevation on the evapotranspiration rate are neglected.

Deep Percolation

The final independent term on the right side of Equation 3.16, G_r, represents the rate of deep percolation. Percolation is simply the movement of water through the soil. Deep percolation is defined to mean water movement through the soil from the plant root zone to the underlying groundwater basin. The dominant potential forces causing water to percolate downward from the plant root zone are gravity and capillary. Water is removed quickly by gravity from a saturated soil under normal drainage conditions. Thus, the rate of deep percolation, G_r, is most rapid immediately after irrigation when the gravity force dominates, and decreases constantly, continuing at slower rates through the unsaturated conditions. Because the capillary potential applies through all moisture regimes, deep percolation continues, though at low rates, even when the moisture content of the soil is less than field capacity (Willardson and Pope, 1963).

Because of a lack of data in the study area regarding deep percolation rates in the unsaturated state and in order to simplify the model, the assumption was made in this study that deep percolation occurs only when the available soil moisture is at its capacity level. In most cases, this assumption causes only slight deviation from prototype conditions. Thus, for this model, the deep percolation rate is expressed as:

$$G_r = F_r - ET_{cr} \;,\; [M_s(t) = M_{cs}] \quad . \; (3.30)$$

$$G_r = 0 \;,\; [M_s(t) < M_{cs}] \quad . \; . \; . \; (3.31)$$

in which all terms are as previously defined.

River Outflow

Using the continuity of mass principle (Equation 2.1) the hydrologic balance is maintained by properly accounting for the quantities of flow at various points within the system. The appropriate translation or routing of inflow water through the system in relation to the chronological abstractions and additions occurring in space and time concentrates the water at the outlet points as both surface and subsurface outflows. As mentioned earlier, active network delays on the computer simulate the long transport times necessary for groundwater inflows and deep percolating waters to be routed to the outflow gaging station.

Thus, the total rate of water outflow from a subbasin is obtained through the summation of various quantities as follows:

$$Q_o = Q_{is} - W_{tr} + OF_r + Q_{oga} - Q_e \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (3.32)$$

in which

Q_o = total rate of outflow from the system
Q_{is} = rate of total surface inflow to the subbasin including both measured and unmeasured flows
W_{tr} = total rate at which water is diverted from the stream or reservoir
OF_r = total of overland flow and interflow rates
Q_{oga} = rate of outflow from the groundwater basin of deep percolating waters, G_r, after routing
Q_{ob} = rate of outflow from the groundwater basin of ungaged subsurface inflows, Q_{ig} (u), after routing
Q_e = rate of water diversions from surface sources for use outside the boundaries of the subbasin. Exports to other drainage basins fall within this category.

If subbasins are selected so no flow of subsurface water past the gaged outflow point exists, the hydrograph of surface outflow, Q_{os}, is given by Equation 3.32. This situation is assumed to exist at the various reservoir sites within the Upper Basin because of construction measures taken to eliminate subsurface flows under the dams which create the reservoirs. For this reason, whenever possible, subbasins were terminated at the outfall of a reservoir. These sites furnished a check on estimated groundwater inflow rates to the subbasin as predicted from verification studies involving models for one or more upstream subbasins.

For many subbasins the termination or outlet point was taken at a Geological Survey gaging station, and in several of these cases groundwater flow occurs in the streambed alluvium beneath the surface channel. For these basins, the total system outflow can be written as:

$$Q_o = Q_{os} + Q_{og} \quad . \; . \; . \; . \; . \; (3.33)$$

in which

Q_{os} = rate of surface outflow from the subbasin
Q_{og} = rate of subsurface or groundwater outflow from the subbasin

Surface outflow rates, Q_{os}, can be compared to the recorded values (U.S. Geological Survey, 1954, 1964, 1961-1967), but subsurface outflow rates, Q_{og}, are unmeasured and must be predicted or estimated. In this study it was assumed that the subsurface outflow rates were directly proportional to the total outflow rates, and Q_{og} was estimated by the following relationship:

$$Q_{og} = k_d Q_o \quad . . . . . (3.34)$$

in which

k_d = a constant determined by model verification representing the percentage of total outflow which leaves the basin as subsurface flow

Because of storage and permeability effects, fluctuations in groundwater flow rates tend to be much less extreme than in the case of surface flows. The value of k_d in Equation 3.34 was, therefore, not maintained as a constant, but was expressed as an inverse function of the surface flow rate, Q_{os}. During the spring runoff period, for example, the predicted increases in subsurface outflow rate, Q_{og}, from Equation 3.34 were considerably less extreme than the increases in observed or computed surface flow rate, Q_{os}. Relationships expressing k_d as a function of Q_{os} were developed for each subbasin through the model verification process. These relationships were programmed on the computer by means of a function generator. Average values of k_d for each subbasin are included in Appendix H.

CHAPTER IV
MODEL OF TOTAL DISSOLVED SOLIDS FLOW

In general, any change which brings about a new equilibrium in the water quantity system also brings about a corresponding alteration in the quality system. In other words, the extent of a change in water quality, such as that caused by the injection of materials at point sources, depends upon the dynamic characteristics of the hydrologic system and the prevailing water-use patterns within the basin. An increase in water quantity within a system subject to a particular use pattern usually improves water quality. By the same token, increased or repeated usage of water of a fixed quantity usually degrades its quality. This statement is particularly true when non-degradable substances, such as salts, are added to the water by use. Thus, the quantity and quality flow systems are closely linked, and management of the quality system must also consider the quantity or hydrologic system.

This study was concerned with developing the basic concepts and relationships for a mathematical simulation model of the hydrologic-salinity flow system within a river basin. The objective was accomplished by superimposing the salinity (total dissolved solids) model upon that of the physical or hydrologic system. The two models are linked by relationships which express water salinity as a function of water flow rate. The rate of salt flow at any point in the system is then estimated by multiplying the water flow rate at that point within the hydrologic system by the appropriate concentration of total dissolved solids (salinity level).

The close association between the hydrologic and salinity flow systems is illustrated by Figures 3.1 and 4.1. Except for the absence of salt movement with precipitation (considered negligible) and evapotranspiration the two systems are coincident. The various hydrologic inputs to the system, such as river, tributary, import, and subsurface inflows, transport given quantities of salt to provide a mass rate of salt inflow to the system. As these input waters are routed, delayed, and used, their salinity concentrations change. In addition, the subsurface components of the total salt inflow function may undergo various time delays in moving through the system. Salt outflow rate functions are then generated through modifications to the input functions of salt by abstractions, additions, and storage changes within the hydrologic system as it moves the salt through the basin, and from additional salt pickup within the basin. Because salinity is a conservative parameter, the problem of modeling involves maintaining a mass salt balance throughout the system. For example, if the TDS concentrations of all hydrologic flow inputs to a system are known, a salt balance is assumed, and ionic exchange and chemical precipitation phoneomena are ignored, the concentrations at the outflow station as altered by water uses within the system can be estimated. Transpired and evaporated waters transport no salts, so that these processes simply increase the salinity concentrations. A thorough and short time mixing of the inflows of differing concentrations was assumed to occur in the model, and it was considered that in most cases the model time increment of one month was sufficiently long to support this assumption.

The preceding comments outline a brief synopsis of the logic and concepts underlying the development of the salinity flow system model. Details of the approach adopted for this study are presented later in this chapter. First, however, some of the general aspects and characteristics of water quality are considered.

General Characteristics of Water Quality

All waters from surface streams and groundwater sources contain dissolved substances known chemically as salts. The term salinity has been used broadly to refer to these dissolved salts. Throughout this report both salinity and total dissolved solids are used interchangeably to refer to the soluble solids transported by water flows.

When water comes into contact with various solid-phase materials, or when waters containing unlike salinity compositions are mixed, chemical reactions usually occur. Reactions of this nature might produce either a loss of certain constituents through precipitation or an increase if new salts are dissolved. Thus, because of the tendency toward chemical equilibrium, a relationship exists between the salt composition of a natural water and the solid minerals with which the water has been in contact. When an aquifer receives direct recharge

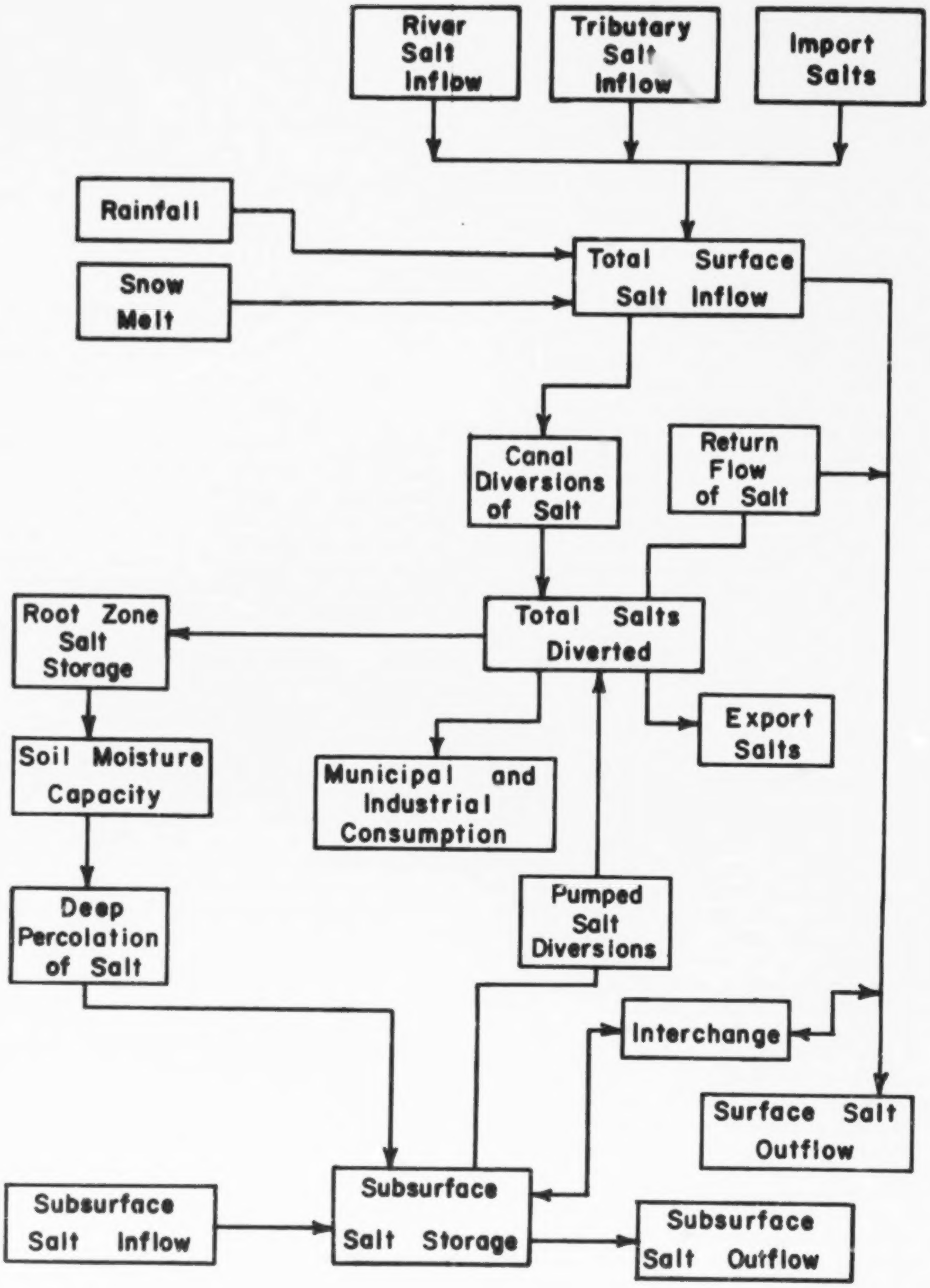

River Salt Inflow
Tributary Salt Inflow
Import Salts
Rainfall
Snow Melt
Total Surface Salt Inflow
Canal Diversions of Salt
Return Flow of Salt
Root Zone Salt Storage
Total Salts Diverted
Export Salts
Soil Moisture Capacity
Municipal and Industrial Consumption
Deep Percolation of Salt
Pumped Salt Diversions
Interchange
Surface Salt Outflow
Subsurface Salt Inflow
Subsurface Salt Storage
Subsurface Salt Outflow

Figure 4.1. Flow diagram for the salinity flow system.

by rainfall, the resultant outflow water from the aquifer portrays a chemical quality characteristic of the alluvium. Somctimes the chemicals that most influence water quality are present in only trace amounts in the rock. A good example is igneous rock which consists mainly of relatively stable and insoluble siliceous minerals, but which also contains traces of other minerals that are readily soluble in water.

Groundwaters nearly always contain greater concentrations of total dissolved solids than do the surface waters in the same region. For a given rock material the rate at which it is dissolved by water is relatively constant. The total amount of material dissolved is largely governed by time and area of contact between the rock and water. Groundwaters percolate slowly through the surrounding alluvium. Thus, the water is exposed to relatively large areas of the surrounding rock for relatively long periods of time. The presence of dissolved carbon dioxide in groundwater may increase the rate at which some minerals, particularly calcium and magnesium carbonates and bicarbonates, are dissolved. Certain characteristics of a groundwater's quality may be far superior to the quality of the surface water. Groundwater is generally free of suspended solids, pathogenic organisms, and other organic pollution, and temperature fluctuations are usually slight. On the other hand, odor, low dissolved oxygen, and total dissolved solids are unfavorable characteristics sometimes associated with groundwaters.

The composition of a natural water can be altered by factors of a biologic nature. Since all forms of life on the earth are dependent upon water for their existence, many of the life processes of plants and animals may considerably influence the composition of water. A great deal of this change occurs in the soil where much of the activity of land dwelling animals and plants occur. The nitrogen cycle and its accompanying bacteria strongly influence processes within the plant root zone, including reactions between water and minerals in the soil.

Man's development of the water resources of the earth has brought about extensive changes in water quality. His intervention in the natural hydrologic pattern of an irrigated area affects both the quantity and quality of surface and underground waters. Evaporation and transpiration decrease the quantity of water available to carry a particular salt load. This in turn tends to increase the concentrations of soluble salts within both surface and subsurface effluents from an irrigated area. Fertilizers and soil amendments also change the quality of the effluent water and sometimes greatly increase the nitrate concentration in the groundwater.

Within the watershed of the Upper Colorado River basin are large areas of shallow shale deposits laid down in the bottoms of ancient lakes or seas in early geologic ages. These shale deposits contain substantial quantities of soluble salts, and many of the soils have inherited this characteristic from the parent shale. In the soil the salts are readily dissolved by water movement across or through the soil profile, and these dissolved salts in turn, are transported by the river systems until they eventually reach the ocean.

Through his irrigation practices man diverts salts already dissolved within the streamflow and applies them to agricultural lands. If these salts are permitted to accumulate within the soil root zone, the lands quickly become saline and plant growth is either retarded or stifled. This condition is prevented by applying an excess of irrigation water such that the salts are carried back to the streams with the irrigation return flows. The net effect of this process is that water flow rates in the streams are reduced by crop evapotranspiration, while salt loads either remain fixed or increase by additional pickup of salts from within the soils of the irrigated area. The question arises as to whether the concentrating effects of evapotranspiration are a form of pollution. In any case, irrigation poses a water quality management problem because the salts must be removed from the agricultural system without at the same time producing unacceptably high downstream salinity levels.

The concentration of dissolved solids in water constitutes only a fraction of one percent of the total weight considered. Hence, quantities of dissolved solids are often expressed in parts per million (ppm), where one ppm means one part by weight of dissolved matter in a million parts by weight of solution. Another measure of dissolved solids common in laboratory analysis is milligrams per liter. Parts per million and milligrams per liter are numerically equal if the specific gravity of the water is unity. In this study dissolved solids are referred to in terms of parts per million (ppm). A further unit of measurement frequently applied to the dissolved solids content of water is equivalents per million (epm), or more exactly milligram equivalents per kilogram. Equivalents per million (epm) are calculated by dividing parts per million (ppm) by the equivalent weight of the ion under consideration. This unit, primarily utilized if figuring the ionic exchange capacities of soil, is useful in managing an irrigated system.

The salts dissolved within a water consist of various cations and anions which together comprise the salinity level. The principal cations include calcium, Ca; sodium, Na; magnesium, Mg; and potassium, K. The main anions are chlorides, Cl; sulfates, SO_4; bicarbonates, HCO_3; carbonates, CO_3; and nitrates, NO_3. The epm calculation is useful in checking the accuracy of a chemical analysis because on a chemical equivalent basis the sum of the cations must equal the sum of the anions.

The quantity of dissolved solids is usually established by standard laboratory analysis techniques. However, when a high degree of accuracy is not required, measurement of the electrical conductance, EC, of a water sample is a convenient and easy method. Chemically pure water in liquid form has a low electrical conductance. However, the presence of dissociated ions in solution renders the solution conductive. Natural waters are solutions of mixed salts, containing some undissociated substances reported as part of the dissolved solids. The dissociated salts have differing relations between concentration and conductance, since the undissociated substances are non-conducting. Although variations are sometimes considerable, Hem (1959) outlines the following empirical relationship between ionic concentrations and conductance:

$$EC = ppm/k_e \cdot \cdot \cdot \cdot \cdot \cdot \quad (4.1)$$

in which

EC = electrical conductance in μ mhos at 25 C

ppm = parts per million

k_e = constant normally ranging between 0.55 and 0.75 but often selected at 0.64, unless the water has an unusual composition of dissolved solids.

River and Tributary Inflows

As mentioned previously, the confining area for the model of this study is the valley floor. For this reason, inputs are not considered in the model until the boundary of this area is reached, at which point the levels of total dissolved solids in the various inflowing waters are measured or estimated. Already many of the processes which contribute to the total quality characteristics of the water have occurred. Soluble products from rock weathering and decomposition are now carried by the water. This solubility process has often been referred to as "solvent denudation." The process of solvent denudation exists to some extent on practically all minerals, and is greatly increased by dissolved carbon dioxide, which is present in most natural waters. Some carbon dioxide is dissolved in rain drops as they fall through the atmosphere. In addition, carbon dioxide is produced in the water bearing soils through the decomposition of organic matter. The solvent denudation process begins, therefore, when water first enters the hydrologic system. The water then moves downward as both surface and subsurface flows and the geologic strata of the drainage area begin to influence the chemical composition of the soluble salts carried by the moving water. Because all rock formations are to some extent soluble, translation of water downward towards the basin outlet inevitably produces an increase in salt concentrations within the water. Both hydrologic and geologic factors influence water quality. The geology of an area describes the characteristics of the rocks within a drainage area. The hydrology, on the other hand, designates to a considerable extent the degree to which these rocks are exposed to the weathering processes of water. For example, when high runoff occurs in the spring months, the flows exhibit their most favorable chemical water quality characteristics because of the rapid runoff rate and short contact time with the surrounding rock surface of the drainage area. Although the water may contain large amounts of suspended material, concentrations of dissolved substances are usually much lower than at other times of the year.

Regardless of the upstream processes that contribute to the quality of inflow water, for the model of this study salinity concentrations are considered only at the point of entry to the valley floor (model area). It is emphasized, however, that an understanding of the watershed surface geology and hydrology (routes followed by the moving water on the drainage area) is essential to estimating the quality of inflows for which no sampling records are available. For example, salinity levels of groundwater inflows usually are considerably higher than those of surface inflows. The quality characteristics of each element of total hydrologic inflow are further discussed in the following sections.

Surface inflow

The surface input of salt consists of the soluble salts dissolved within the water traveling over the ground surface and through the tributary channels of the subbasin. As indicated by Equation 3.5, the total inflow rate of surface water is made up of two components, namely measured flows, $Q_{is}(m)$, and unmeasured flows, $Q_{is}(u)$. The surface salinity flow system also contains these same two components of measured and unmeasured flow rates. Not always do the two components coincide between the water and salinity flow systems. For many subbasins within the Upper Colorado River basin the number of streams for which water flow records are available exceeds the number of streams that are being monitored to provide water quality data. In other words, although the streamflow is being measured on all streams for which salinity records are available, the reverse is not always true. Thus, as a general statement,

$$\sum_{j=1}^{n} q^{j}_{is}(m) \leq Q_{is}(m) \cdot \cdot \cdot \cdot \quad (4.2)$$

in which

$q^{j}_{is}(m)$ = the measured surface water flow rate in any tributary, j

n = the number of surface streams in the subbasin for which both water flow and salinity records are available

Considering only surface streams for which both the quantity and quality are measured, the "measured" mass rate of salt inflow through the surface system is estimated as follows:

$$S^{is}_{r}(m) = \sum_{j=1}^{n} q^{j}_{is}(m)\, C^{j}_{i}(m) \cdot \cdot \quad (4.3)$$

in which

S^{is}_r (m) = rate of salt inflow to a system associated with measured salinity levels and surface water inflows

C^j_{is} (m) = measured total dissolved solids concentration associated with the measured surface water inflow of tributary j

The quantity S^{is}_r (m) includes any rate of surface salt inflow (measured or computed) from an adjacent upstream subbasin.

Salt inflow rates to a given subbasin associated with the unmonitored surface waters are estimated by establishing appropriate salinity concentration levels. The unmonitored surface inflow waters are divided into two categories:

(1) Those streams for which measured water flow rates are available but for which quality data are not available. This rate of flow is designated as ΔQ_{is} (m) and is given by the following equation:

$$\Delta Q_{is}(m) = \sum_{j=1}^{k} q^{j}_{is}(m) \quad . . . \quad (4.4)$$

in which

k = the number of surface streams in the subbasin for which water flow records are available but salinity records are lacking

Limiting conditions for Equation 4.4 are specified by Equation 4.2 and occur when n = k. Q_{is} (m) is given by summing the term q^j_{is} (m) across both k and n.

(2) The total ungaged inflow rate of surface waters, Q_{is} (u).

Salinity concentration levels required for the two components of flow ΔQ_{is} (m) and Q_{is} (u) were estimated from surface geology information and available salinity records. It was assumed, for example, that all water emanating from areas of similar hydrologic and geologic conditions would exhibit similar quality characteristics. On the basis of this assumption, salinity levels were estimated as required from the records of monitored streams lying both within and outside the particular subbasin under consideration. Difficulties were encountered in a few subbasins containing areas which are subject to significant levels of runoff from thunderstorms. The resultant "flushing" action of the high water flows moves large quantities of salt from the watershed in a short time period. To account for this phenomena, average monthly salinity concentrations in the streams were set at higher levels than normally would be expected.

The ungaged salt inflow to a given subbasin associated with the water inflow quantity ΔQ_{is} (m) is now estimated by the following relationship:

$$S^{is}_{r\Delta Q}(u) = \sum_{j=1}^{k} q^{j}_{is}(m)\, C^{j}_{is}(u) \quad . . . . \quad (4.5)$$

in which

$S^{is}_{r\Delta Q}$(u) = rate of salt inflow associated with those surface streams for which hydrologic but not quality data are available

C^j_{is} (u) = estimated salinity concentration associated with tributary j

The term q^j_{is} (m) has been previously defined.

Similarly, the rate of salt inflow associated with the ungaged surface water inflow to a subbasin, Q_{is} (u), is given by:

$$S^{is}_{r}(u) = Q_{is}(u)\, \bar{C}_{is}(u) \quad . . \quad (4.6)$$

in which

S^{is}_r (u) = rate of salt inflow associated with surface waters for which hydrologic and quality data are not available

$\bar{C}_{is}$ (u) = a weighted average salinity concentration associated with the ungaged surface water

The average salinity concentration, $\bar{C}_{is}$ (u), is weighted on the basis of the aerial distribution (geology of drainage area) and the estimated relative flow rates from each source area.

The total surface inflow rate of salt to a subbasin is estimated by summing Equations 4.3, 4.5, and 4.6.

In the preceding development of relationships for predicting the surface rate of salt input to the valley floor of a subbasin, heavy reliance was placed on available salinity measurements. The usefulness of the model for management and operation studies would be increased if relationships for predicting salinity levels as functions of, for example, geology and hydrology, could be developed and included in the model. Iorns et al. (1965) developed characteristic water flow versus salinity curves for several stations of the Upper Colorado River basin. In this study statistical techniques were used in an attempt to develop predictive equations for salinity at various stations within the upper basin. The independent variables were mean monthly water discharge and time (month). In some cases, good correlations were obtained, and the relationships were used to extend quality records as required at the stations. The relationships are also available for incorporation into the computer simulation models of the appropriate subbasins.

Further research is needed to improve relationships for predicting water quality as a function of parameters such as various watershed characteristics and hydrology. Because of the complex processes which occur in a watershed, it is likely that these relationships will need to be empirical in nature. However, additional quantitative definition of the vital link between the hydrologic and quality flow systems is essential to efficient water resource management. As improved relationships are developed, they can be incorporated into system models of the kind developed in this study. The procedures and digital computer program used in the development of quality predictive equations are discussed in Chapter VI.

Groundwater inflow

The subsurface rate of salt movement into the valley floor area of a subbasin is estimated by assigning an average salinity concentration value to the rate of groundwater inflow, $Q_{ig}(u)$, as estimated by Equation 3.6. Thus

$$S^{ig}_{r}(u) = Q_{ig}(u)\ C_{g}(u) \quad . \ . \quad (4.7)$$

in which

$S^{ig}_r(u)$ = rate of unmeasured salt inflow to a subbasin through the groundwater system

$C_g(u)$ = average water salinity level associated with the unmeasured groundwater inflow to a subbasin

During periods of low flow, much of the water flowing in a surface stream consists of effluent flow from the groundwater basin of the watershed. Thus the quality of the base flow carried by a stream is often a good indicator of groundwater quality of the watershed. In most cases the salinity concentration, $C_g(u)$ in Equation 4.7, was estimated from the average value of the salinity level in the intrasubbasin streams during the base flow period. In some cases groundwater salinities could be estimated by a hydrograph separation technique proposed by Iorns et al. (1965). Under this technique flow duration curves are used to divide the total runoff hydrograph at any point in a stream into the two components of base flow and direct runoff. If the salinity concentration of the total flow is known, the salinity of each component of the hydrograph then can be estimated. The value of $C_g(u)$ as estimated by either of these two procedures is considered to be average in terms of both time and space.

Equation 3.6 estimates the rate of groundwater inflow, $Q_{ig}(u)$, to the alluvium beneath the soils of the valley floor. This rate of flow, however, refers only to waters originating within the subbasin under consideration. As indicated in Chapter III, for many areas there is additional subsurface water inflow from the adjacent upstream subbasin (Equation 3.34). With reference to both the hydrologic and the salinity flow systems rates of inflow are, of course, equal to previously established outflow rates from the upstream subbasin. Thus, the total rate of subsurface salt inflow to a particular subbasin is a summation of the quantity $S^{ig}_r(u)$ from Equation 4.7 and any underflow from the upstream subbasin.

Total inflow

The total inflow rate of salts, S^i_r, to a subbasin consists of the summation of all surface and subsurface inputs. Thus, by summing those rates of flow estimated by Equations 4.3, 4.5, 4.6, and 4.7:

$$S^{i}_{r} = S^{is}_{r}(m) + S^{is}_{r\Delta Q}(u) + S^{is}_{r}(u) + S^{ig}_{r}(u) \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (4.8)$$

in which all terms have been previously defined. The total rate of salt inflow estimated by Equation 4.8 excludes any subsurface inputs from an adjacent upstream subbasin. Surface flows from an upstream subbasin are included in the term $S^{is}_r(m)$. Subsurface, or undergage, salt flow rates from an upstream subbasin are estimated during the model verification procedure for that subbasin. The flow rate function thus developed represents a subsurface input to the adjacent downstream subbasin. The total estimated salt inflow rate to this subbasin is then given by summing the quantity S^i_r from Equation 4.8 with the subsurface output function from the adjacent upstream subbasin.

Precipitation

The primary mechanism under which precipitation occurs is through the condensation of water on hygroscopic nuclei in the atmosphere. Sodium chloride particles and dust are examples of the nuclei around which each drop of rain forms. In addition, falling precipitation gathers minute traces of various minerals, dissolved gases, and other elements. In the practical sense, the relative volume of salts which enter a hydrologic system through precipitation is usually so small that a salt input from this source has been neglected in this study.

Once precipitation has entered the hydrologic system, the various phases of runoff begin to occur. The importance of precipitation to the salinity system results from the residual portion of runoff that occurs from some point within the hydrologic system. The salt inflow from this source is already described by Equation 4.8. However, the most favorable chemical water quality characteristics within the Upper Colorado River basin occur during the spring months when rapid runoff is produced by the melting snows. Precipitation which falls directly on the valley floors infiltrates the soil and through the weathering process also contributes to the quantity of total dissolved solids further downstream.

Temperature

The effect of temperature upon the salinity flow system is secondary in nature. The solubility of a given element of salt in water is a function of temperature and various other factors, such as pressure, pH, and the relative concentrations of other substances. Temperature affects the solubility of minerals less than that of gases. For gases, including carbon dioxide, the solubility limit increases as water temperatures fall. Dissolved carbon dioxide shifts the carbon-dioxide-carbonate-bicarbonate system so that more material, such as calcite, is dissolved as the level of dissolved carbon dioxide rises. As water temperatures rise, the level of molecular activity is raised so that chemical reactions occur at increased rates, thereby accelerating the solvent denudation process. Various other temperature effects exist but all are microscopic in nature so that under normal conditions the usual temperature differences within a given region probably have an insignificant effect on mineral solubilities.

Water temperatures also influence other processes within a hydrologic system. The water holding capacity of soil is slightly reduced by increased temperature. Temperature also affects the solubility of ions within the soil solution and their availability to plants. Within the aquatic-ecological system marked temperature changes are detrimental to fish and other plant and animal organisms.

Because of the macroscopic scale of the salinity model of this study, direct temperature effects of the kind discussed in the preceding paragraphs are insignificant. However, air temperature is used in the model as an index of available energy for the evapotranspiration process and in this indirect sense temperature considerably affects salinity levels within the flow system.

Canal Diversions

Irrigation water diverted to agriculture lands transports dissolved solids from the source of supply. Some salt abstractions from this diverted flow occur through seepage losses in the conveyance system. Since the assumption is made that the irrigation water is uniformly mixed, the proportion of salt lost from the conveyance system through seepage is equal to the proportion of the water seepage loss.

Through contact and exposure to soil surfaces, the diverted water may dissolve some additional solids as it moves from the diversion point to the place of application. However, unless water quality measurements are made at various points along the conveyance system, the degree of salinity increase from this source cannot be properly assessed. In general, for most distribution systems it can be correctly assumed that the salinity of the water reaching the irrigated lands is essentially the same as that at the diversion point. This assumption was applied for all irrigation systems in this study.

Salinity levels at all points of diversion within a subbasin were taken as being equal to the salt concentrations within the stream or river inflows to the area. This treatment was necessary because the entire agricultural area within each subbasin was modeled as a single space increment. For most subbasins canal intakes are situated near the salinity monitoring stations on the inflowing streams.

The rate at which salt is carried into the soil by irrigation waters can be estimated by rewriting Equation 3.12 and multiplying it by the concentration of dissolved solids in the diverted water. The expression, including the modified irrigation efficiency parameter discussed earlier, is written:

$$S_r^{W_{dr}} = \left[\frac{W_{tr}(Eff)}{100}\right] C_i(m)$$

$$= W_{dr} C_i(m) \quad . \ . \ . \ . \ . \ . \ . \ . \quad (4.9)$$

in which

$S_r^{W_{dr}}$ = rate of diverted salt inflow to the soil by seepage and infiltration
W_{tr} = total rate at which water is diverted from the stream or reservoir
Eff = water conveyance and application efficiency in percent
$C_i(m)$ = average salinity level of measured surface water inflow to the system
W_{dr} = rate at which diverted water enters the soil through seepage and infiltration

If a salt balance is maintained in the system, the salt represented by Equation 4.9 eventually returns to the river or stream by way of deep percolation and interflow.

Effects of Dissolved Solids on Agriculture

Water containing excess soluble salts tends to impose extra burdens on the agriculture enterprise. As discussed by Bishop and Peterson (1969), high salinity levels generally reduce plant growth and yield, require additional water to maintain a salt balance, and may require the adoption of special irrigation and drainage practices.

Several criteria have been proposed for classifying waters according to their suitability for irrigation. Most criteria have considered the quality parameters of total salinity, and the specific ions of sodium, boron, and the carbonates. The equation proposed by the U.S. Salinity Laboratory (Richards, 1954) is a typical classification criterion for irrigation waters. The sodium-adsorption ratio (SAR) proposed by this equation considers both the sodium ion and total salt concentrations in the water. Later, Doneen (1959) suggested a classification based upon "effective salinity," in which the relatively insoluble salts of calcium bicarbonate, magnesium bicarbonate, and calcium sulfate are not considered in the total salinity of the soil solution. Recent criteria for classifying irrigation waters also consider pollutants not normally found in natural waters. Some of the specific effects of total dissolved solids or salinity upon the agriculture enterprise are noted in the following paragraphs.

Infiltration

Under normal conditions the quantity of dissolved salts in water has little influence upon infiltration rates. However, leaching of sodium cations from soils containing high levels of exchangeable sodium cause these soils to dispense, or deflocculate, and this reduces infiltration rates. Deflocculation of the soil particles can be reduced by replacing the exchangeable sodium with calcium. The exchange occurs because soils have a greater affinity for the bivalent ions, calcium and magnesium, than for the monovalent ions, sodium and potassium.

Most agricultural soils within the Upper Colorado River basin contain a predominance of the calcium ion in the exchange complex. Thus, infiltration rates were considered to be unaffected by salinity levels of the irrigation waters.

Plant responses to salinity

The most marked effect of high total dissolved solids levels in irrigation water is a lowered agricultural production resulting from impaired plant growth. Generally speaking, crop production is affected when the salinity of the soil solution within the root zone exceeds crop tolerance levels (Richards, 1954).

In Chapter III the water holding characteristics of various soils were discussed. Consideration was also given to some of the forces which must be overcome by plants in extracting moisture from the soil for physiological development. The soil moisture supply available to plants is drawn primarily from that water surrounding the soil particles, and the total force with which this water is held by the soil is designated as soil moisture tension. As the supply of soil moisture decreases, this tension increases, and the force which must be exerted by the plant to withdraw water from the soil correspondingly increases. Ultimately the plant is unable to extract water at a rate sufficient to meet potential evapotranspiration requirements and wilting occurs.

Dissolved solids in the soil moisture tend to increase osmotic pressures and thereby reduce the effectiveness of the plant root system for extracting water from the soil. Thus, an increase in salinity level within the soil solution increases the effective moisture tension to the plant for a given soil classification and a particular soil water content. This effect is shown by Figure 4.2 which is taken from a study by Wadleigh and Ayers (1945). The total soil moisture stress (moisture tension plus osmotic pressure of the soil solution) is plotted in relation to the percentage of moisture in the soil at various salinity levels in the soil solution. The salt in this study consisted of one half calcium chloride and one half sodium chloride. Figure 4.2 indicates that for a permanent wilting point of 15 atmospheres, the percentage of unavailable water retained in the soil increased from approximately 6 to 10 percent as the salt content of the soil solution increased from 0 to 0.4 percent. At field capacity the same salinity increase raised the stress required by the plants to obtain moisture from 1 to 7 atmospheres.

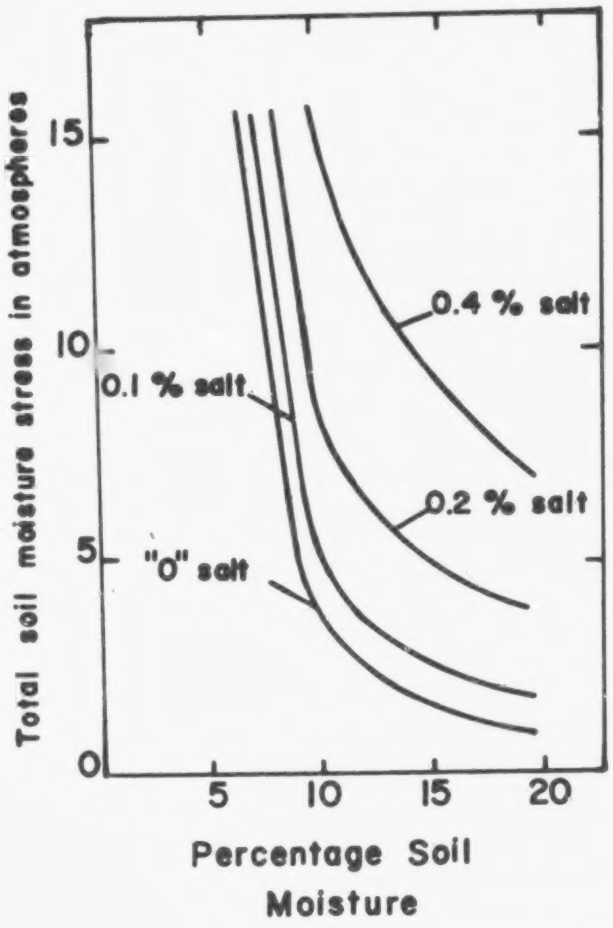


Figure 4.2. Relation of moisture tension to moisture percentage at different soil salinity levels (Redrawn from Wadleigh and Ayers, 1945).

Other processes which influence plant growth are chemical precipitation and ionic exchange within the root zone. For example, precipitation of calcium carbonate salt in the presence of the bicarbonate ion leaves the sodium salt in solution, thus producing a sodium hazard. Ionic exchange also might alter the relative concentrations of calcium and sodium in the soil solution.

In some cases plants are also damaged by toxic substances in irrigation waters. Such phyotoxic substances include chlorides, bicarbonates, trace elements, heavy metals, and especially boron. All plants require traces of many elements for proper physiological development, but the extent to which these elements are required, and the plant tolerance limit to each, varies with plant species. Boron tolerance for various plant species has been extensively studied (Richards, 1954), but little is yet known about tolerance levels for other elements. Most crops require a relatively well-balanced nutrient content in the soil solution (Bishop and Peterson, 1969). High concentrations of salts may upset the balance in composition and create unfavorable conditions for plant growth.

In general, the tolerance of growing vegetation to salinity is largely a function of species. Furthermore the effect of salinity is often more pronounced on a plant species in its germination or seeding stage than in later stages of plant development. Sugar beets, for example, are particularly intolerant to high salt concentrations at the time of germination.

Evapotranspiration

The most important factor relating evapotranspiration and water quality is the fact that the water consumed by plants is essentially pure. The dissolved solids in the soil solution either precipitate in the soil or remain dissolved in the portion of the water not consumed. Thus, the evapotranspiration process concentrates the original salt load in the soil solution. If sufficient deep percolation occurs, these dissolved solids are carried from the root zone and a salt balance is maintained. However, when irrigation applications do not exceed the field capacity of the soil in the plant root zone, only limited amounts of deep percolation occur and salts remain in the soil. Under these conditions some ion exchange and salt precipitation take place, but the net effect is an increasing salinity concentration in the soil solution. As previously discussed, this trend raises osmotic pressures, and thus increases the energy required by the plants to extract water from the soil. Hence, although the total quantity of water available in the soil regime is not affected by the total dissolved solids, plant soil moisture stresses are increased by the raised osmotic pressures. Irrigation practices which do not maintain a salt balance in arid regions by more than meeting evapotranspiration requirements eventually cause the land to become unproductive.

Salt balance

The concept of a general salt balance within a hydrologic system was first proposed by Schofield (1940). Under this concept the total quantity of soluble salt introduced into an area, plus increases within the area from weathering and other sources, must equal the amount of salt discharged in the outflow water from the area. If a salt balance is not maintained within an irrigated area, for example, under conditions of inadequate drainage, the land eventually becomes unproductive because of high salinity conditions within the soil solution. These conditions are prevented by the application of water in excess of that required by the crop. Adequate drainage conditions must exist so that this excess water moves through the soil profile carrying with it a load of dissolved salts. The leaching requirement for a soil is defined by the U.S. Salinity Laboratory (Richards, 1954) as the proportion of total irrigation water required to drain through the soil in order to maintain a favorable salt balance. He expressed this leaching requirement in the form of a ratio:

$$LR = D_{dw}/D_{iw} = EC_{iw}/EC_{dw} \quad . . . (4.10)$$

in which

LR = leaching requirement

D_{dw} = depth of drainage water

D_{iw} = depth of irrigation water

EC_{iw} = average electrical conductance of the irrigation water

EC_{dw} = average electrical conductance of the drainage water

Under average conditions the application of 30 or 40 percent more water than that required by the plants for transpiration will prevent the accumulation of salts in the soil. The salt balance concept is an important management principle for perpetuating agricultural production on irrigated land.

A basic simplifying assumption made in this simulation study is that a salt balance exists in each subbasin. In other words, the ionic exchange and chemical precipitation phenomena are not included in the model. Justification for this assumption is based primarily on the observation that within most subbasins of the Upper Colorado River basin annual irrigation diversions are approximately 10 to 20 acre-feet of water per acre of land. In general, under diversion rates of this magnitude leaching is sufficient to maintain a salt balance within the system.

The dissolved solids transported by the water move through the system along various hydrologic flow paths. Throughout this dynamic system salinity concentrations are increased by both evapotranspiration and the addition of other dissolved solids to the solutions. For example, those waters which deep percolate to the groundwater basin assume a salt load indicated by the groundwater concentration. Thus, in the model of each subbasin an input-output salt balance is maintained to consider changes, additions, and short time delays in salt loading within the subbasin.

Return Flow

In this study return flow is considered as that part of total irrigation diversions which ultimately returns to the stream system. As discussed in Chapter III, the three major components of return flow are overland flow, interflow, and groundwater outflow.

The intricate nature of the water-soil-salt complex produces difficulties and uncertainties in predicting both the quantity and the quality dimensions of return flow water. The quantity of flow which returns from the agricultural system is a function of such variables as the quantity diverted, canal seepage, soil characteristics, precipitation, crop type, evapotranspiration rates, and various farm practices including application rate and method. Many of these same parameters also influence the quality of return flow. However, Bishop and Peterson (1969) indicate that the composition and quantity of the applied irrigation water are usually the primary factors which influence the quality of the return flow. It is basically these two parameters which are considered by this model study. Other factors which might affect return flow quality, such as the concentration of the soil solution, ionic exchange, and precipitation reactions, are neglected.

It is apparent that the quality of irrigation diversions significantly affects the quality of return flows. Perhaps less obvious is the influence of diversion quantities in relation to irrigation requirements. The quality of return flow depends upon both the time and degree to which the water has been exposed to surfaces which might increase salinity. Returning waters which receive limited exposure to soil surfaces throughout the irrigation system will carry only slightly more total dissolved solids than at the point of diversion. On the other hand, water which moves through the soil profile in the dynamic soil moisture regime is exposed to large soil surface areas for relatively long periods of time. Thus, opportunities are provided for solids to dissolve and for ionic exchanges to occur. These phenomena, coupled with the concentrating effects of the evapotranspiration process, produce concentration levels in the soil solution which are generally about four to ten times higher than those of the irrigation water at the point of diversion (Bishop and Peterson, 1969). This same reference indicates that drainage from the root zone, when restricted by a high water table, might carry concentrations ranging from 40 to 80 times those of the irrigation water.

As might be inferred from the preceding paragraph, under conditions when irrigation diversion rates are high in relation to evapotranspiration requirements, return flow rates are also high and salinity concentrations in all components of the return flow are usually relatively low. In particular, for situations where the proportion of surface runoff in the total return flow is high, net salinity increases in the agricultural system can be expected to be low. On the other hand, if diversion rates are low in relation to irrigation requirements, salinity concentration increases in return flows are usually high. However, the total rate of salt flow from a system is often greater under high irrigation applications than for low application rates.

Return flows from irrigated areas tend to increase the total dissolved solids load carried by a stream. Often included in this load are quantities of nitrates, phosphates, and pesticides which are added to the irrigated lands to increase crop production. Because conventional treatment methods are ineffective in removing these constituents from water supplies, agricultural use can pose a serious problem to downstream municipal and industrial uses. Certain management techniques can be utilized to reduce undesirable changes in the quality of the receiving water. Bishop and Peterson (1969) suggest several possible measures, which include controlling canal seepage losses, bypassing return flows past critical use areas, controlling the volume of leaching water used, discharging into a closed basin and allowing evaporation to dispose of the unwanted waters, and desalinating return flows. Frequently, control measures of this nature become necessary, and in fact economically feasible, only in the lower reaches of a river drainage system.

Surface runoff and interflow

In the model developed under this study the surface runoff and interflow components of return flow are treated as a single identity. The quantity or rate of flow under this identity is given by Equations 3.13 and 3.14. Multiplying this rate of water flow by the concentration of the return flow produces the following expression for estimating the rate of salt flow carried by the surface runoff and interflow components of return flow.

$$S_r^{OF} = [(1 - \frac{Eff}{100}) W_{tr} + N_r] C_s$$

$$= OF_r C_s \quad . . . . (4.11)$$

in which

S_r^{OF} = rate of salt flow returning from the agricultural area with overland flow and interflow

Eff = water conveyance and application efficiency in percent

W_{tr} = total rate at which water is diverted from the streams or reservoirs

N_r = interflow rate

OF_r = total of overland flow and interflow rates

C_s = average water salinity level of the surface runoff and interflow from irrigated lands or other areas of water use

The value of C_s is estimated either from collected data or by considering concentrations and quantities of the diverted water and the relative proportions of the surface runoff and interflow rates to total rates of diversion. Estimated values of C_s were tested during model verification.

Deep percolation

Deep percolation has been previously defined as water movement from the plant root zone into the underlying groundwater basin. In this study deep percolation is assumed to occur only when the available soil moisture is at the field capacity level. As the water moves downward through the soil profile, not only is the load of total dissolved solids increased, but also a shift in the relative concentrations of the various dissolved constituents frequently occurs (Bishop and Peterson, 1969). This same reference also indicates that the percolation process reduces water borne quantities of colloidial materials, phosphorous, organic substances, and pathogenic organisms. Depending upon relative salinity levels, percolating waters either increase or decrease salinity concentrations in the groundwater basin. In some cases, appreciable quantities of a high quality water may be added to the groundwater supply through unlined irrigation canals. Salinity concentrations within deep percolating waters may be evaluated by collecting samples of the soil solution with respect to both the time and space dimensions.

The rate of salt flow moving with the deep percolating water from the plant root zone can be estimated by multiplying an average salinity concentration by the appropriate rate of water flow. Deep percolation rates may be estimated by Equations 3.30 and 3.31. The accompanying rate of salt flow can then be written as:

$$S_r^G = [F_r - ET_{cr}] \, C_{ga} = G_r C_{ga} \, , \qquad [M_s(t) = M_{cs}] \, . \, . \, . \, . \, . \, . \, . \, (4.12)$$

$$S_r^G = 0 \, , \; [M_s(t) < M_{cs}] \, . \, . \, (4.13)$$

in which

S_r^G = rate of salt flow which deep percolates from the plant root zone

F_r = infiltration rate from the soil surface

C_{ga} = average salinity concentration within the soil solution beneath the agricultural lands

ET_{cr} = potential evapotranspiration rate

G_r = deep percolation rate

M_s = soil moisture storage available to plants

M_{cs} = soil moisture storage capacity within the plant root zone

The value of C_{ga} was estimated during the model verification process.

In general, water movement is slow within the groundwater aquifers. Thus a considerable time period might be required for the deep percolating water, now carrying a salt load associated with the salinity of the groundwater basin, to emerge as effluent flow. The delay time required for this process within each subbasin is estimated through the model verification procedure.

Natural Inbasin Salinity Contribution

In the initial stages of this study it was assumed that the entire increase in total salt flow rate within a subbasin could be attributed to irrigation. However, during the development of the simulation model it was found that the computed mass rate of salt flow leaving each subbasin was usually much less than the measured rate of salt outflow. Although satisfactory verification had been achieved for the hydrologic systems, computed salt outflow rates were often from 2 to 10 times less than the recorded values. The problem was further compounded because within many valleys the computed return flows from agricultural areas were insignificant during the winter and spring months prior to the irrigation season. On the other hand, water salinity measurements indicate that even during these periods dissolved solids are apparently being added to the streams as they flow through the valleys. The question then arose as to the source of this additional and unaccounted for salt flow. Studies by the U.S. Bureau of Reclamation (1967) indicate that along certain reaches of the Colorado River there are large increases in the load of dissolved solids which cannot be attributed to the agricultural system. For example, this reference estimates that the dissolved solids contributed from unaccountable sources within the subbasin immediately upstream from Lee Ferry are equal to approximately 5 percent of the total load at the Upper Basin outlet. These observations emphasize the importance of further studies to identify sources and magnitudes of salinity contributions to the waters of the Upper Colorado River system.

Several hypotheses might be considered as to the source of this additional salt loading. One possibility is that the salts are brought to the valley floor areas by flows of ungaged water. If this water were subsequently lost by evapotranspiration, it would not be reflected in the outflow hydrographs. However, this theory is not supported by events occurring within the hydrologic portion of the system. First, the incremental salt loading does not seem to be related to evapotranspiration rates. Substantial salinity increases occur even during those periods of the year when evapotranspiration rates are minimal. Second, additional ungaged water flow rates needed to transport the required additional salt input to some subbasins were found to exceed from two to ten times the total gaged water inflow rates to the subbasins. It is conceded that within the model phreatophytic and agricultural land areas could be somewhat in error, but consistent discrepancies of the order required in estimating ungaged hydrologic inputs and evapotranspiration rates are not likely. Salt inflow with ungaged hydrologic streams was therefore discarded as being a probable major contributor to the salinity load unaccounted for within the waters of the Upper Colorado River.

Mineral springs represent another possible source of unaccountable salinity within the basin. Iorns et al. (1965) estimate that 182,600 tons of salt annually originate from mineral springs in a 17 mile stream reach between the Eagle River and Shoshone power plant. However, these authors also indicate that this load represents approximately 30 percent of the total annual contribution from thermal springs within the entire Upper Colorado River basin. Apparently contributions from these sources contribute only a relatively small portion of the additional natural salt load required. Further rejection of this theory can be based on the observation that the known locations of mineral springs could not provide the spatial distribution of the additional salt load required by the model. In addition, salt discharge rates from mineral springs are relatively constant. On the other hand, the additional or unaccountable salt load appears to be directly related to water flow rates. Increases in water flow rates, whether originating as reservoir releases, spring snowmelt, or thunderstorms, produce increases in the unaccountable mass rate of salt flow.

The apparent link between water flow rate and the unaccountable mass rate of salt flow led to the hypothesis that within each subbasin substantial interchanges are occurring between surface and subsurface waters. This phenomenon implies that the stream system is both influent and effluent at different locations within the subbasin. An influent stream is one which contributes to the groundwater system, whereas an effluent stream intersects the water table and receives flow from the groundwater system. Most perennial streams are effluent through a portion of their length, and the existence of both conditions in a single reach is common (Linsley et al., 1958). Within the subbasins of the Upper Colorado River influent conditions frequently exist in the upper reaches of the main stream channel with effluent flow occurring farther downstream toward the outlet of a subbasin. It is therefore conjectured that much of the water which enters the alluvium as influent flow in the upstream portion of a subbasin returns again to the stream channel in the lower reaches, and that within a particular subbasin the rate of interchange between surface water and groundwater may be influenced by water levels in the stream channels. Hence, during periods of high streamflow some increase in the interchange rate might be expected.

The dissolved solids content of groundwater is usually higher than that of surface water. Thus, waters entering a stream channel from a groundwater basin increase salinity levels in the surface stream by an amount directly proportional to the difference between the concentrations of dissolved solids within the surface waters and the effluent groundwater. These differences can be appreciable in the Upper Colorado River basin where groundwater salinity levels tend to be high.

The interchange hypothesis can account for substantial increases in the load of dissolved solids carried by the waters of the main surface stream within a subbasin. In addition, under the hypothesis, salinity increases can be expected to be particularly significant in those valleys underlain by large and permeable alluvia. The fact that these same features also characterize areas which are suitable for agricultural production apparently has tended to foster the conclusion that the incremental salt loads added to the stream while flowing through these valleys are attributable largely to irrigation agriculture. Because it is a natural phenomenon, the interchange hypothesis explains salinity increases which occur even during those periods of the year when return flows from agricultural lands in many subbasins are insignificant.

Attempts to model the joint hydrologic-salinity flow systems of several subbasins within the Upper Colorado River basin confirmed the speculation that interchange rates are related to rates of water flow in the surface channels. As a general case, there are other factors which also need to be considered such as channel slope, channel width, stream bed porosity, and geologic conditions. However, the development of a general relationship utilizing these various parameters would represent an extensive study in itself, requiring the collection of much additional data. It was considered to be beyond the scope of this project. The problem was simplified by attempting to establish empirical relationships for each particular subbasin in which the only independent variable included was the rate of water flow in the main drainage channel. Through the model verification process functions were developed for each subbasin relating the rates of streamflow discharge and interchange. Figure 4.3, which illustrates the relationship developed for the White River subbasin, is typical of the kind of empirical function found to apply within each subbasin of the Upper Colorado River. The rate of interchange is expressed as a percentage of the streamflow rate in the main channel of the subbasin. For example, at a streamflow rate of 1,000 cfs within the White River subbasin, the interchange rate is approxi-

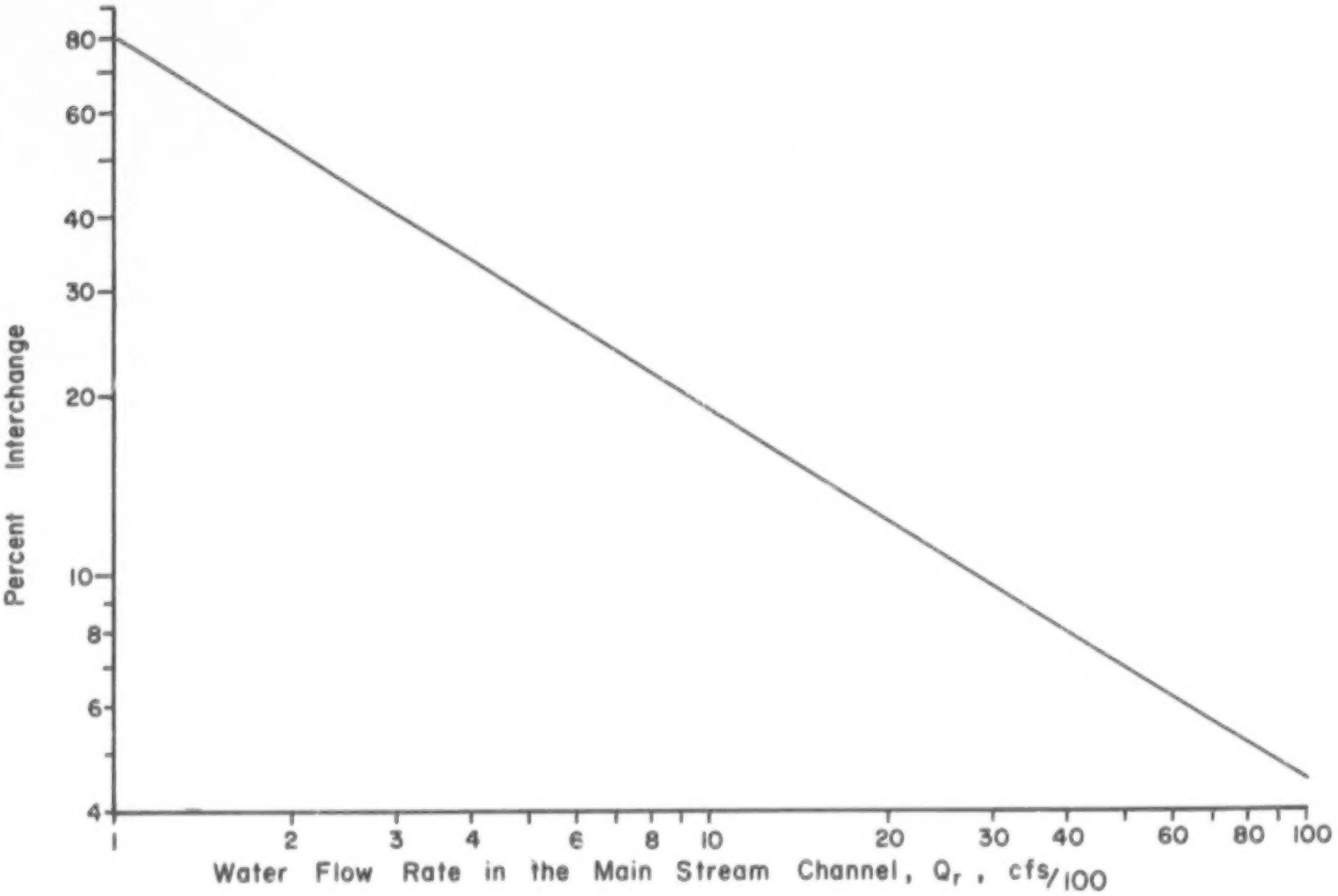


Figure 4.3. Interchange or recirculation plot for the White River subbasin.

mately 200 cfs. The relationship is shown as a straight line on log-log paper, and is expressed in a general form:

$$k_p = n(Q_r)^m \quad \ldots\ldots (4.14)$$

in which

k_p = percentage of surface flow to be interchanged or recirculated through the stream alluvium
Q_r = monthly surface flow rate in cfs
m = slope of line plotted on log-log paper
n = intercept on the y-axis (percentage axis) of a log-log plot

In general, the streamflow rate, Q_r, applied in the application of Equation 4.14 to a particular subbasin was taken as the average between the monthly surface inflows and outflow rates in the main stream channel. However, in each case consideration was given to the relative position within the subbasin of the channel reach where it was considered the major portion of the interchange was occurring. For example, if it were apparent from geologic information that much of the interchange within a particular valley was occurring near the upper end, then the rate of stream inflow was used in the interchange relationship.

From Equation 4.14 the salt flow rate resulting from the interchange process can be written:

$$S_r^{NS} = k_p\, Q_r\, C_g \quad \ldots\ldots (4.15)$$

in which

S_r^{NS} = rate of salt flow contributed from natural sources within the basin
k_p = percentage of surface flow allowed to interchange or recirculate through the stream alluvium or groundwater basin
Q_r = monthly rate of surface water inflow, outflow, or average of inflow and outflow to a subbasin
C_g = average water salinity level within the groundwater basin or stream alluvium of a hydrologic system. This quantity was assumed to be constant throughout the simulation period, and was estimated from the average salinity level of the base flows of the streams within the subbasin.

As groundwater moves through the alluvium material, it continues to dissolve soluble salts. For this reason the total dissolved solids content of water moving in the groundwater system usually increases towards the lower end of the valley. Therefore, in Equation 4.15 the concentration of dissolved solids within the stream alluvium of a groundwater system, C_g, is assumed to be an average value for the entire basin.

Subbasin Outflow

Since the hydrologic and the salinity flow systems are interconnected, the same basic principles underlie movement in both regimes. As with the hydrologic system, the input functions to the salinity system within an area are acted upon by the routing and storage functions of the system. In addition, depending upon concentration levels, salts move in and out of solution and ionic exchanges occur. All of these various processes affect the output salinity function so that concentration levels and mass rates of salt flow at the output may differ considerably from those of the input. Because dissolved solids are non-degradable, the continuity of mass principle described by Equation 2.1 also applies to the dynamics of flow within the salinity system. Thus, the solvent denudation processes within the system frequently produce mass rates of salt flow at the output which are higher than those at the input. Depending upon the hydrologic inputs and the relative effects of the evapotranspiration and the dissolving processes, average concentration levels may or may not be increased at the outflow point.

The various processes within the hydrologic-salinity system occur with respect to both space and time, and the net result of modifications to the input salinity flow system are reflected at the outflow point as a combination of both surface and subsurface salt outflow. As discussed in Chapter III, active network delays are used in the computer model where necessary to simulate the movement of salt as it occurs with respect to time and space within the system.

The total rate of salt outflow from a hydrologic system, $S_r^{Q_o}$, can be estimated by attaching salinity levels to the hydrologic quantities on the right side of Equation 3.32, thus:

$$S_r^{Q_o} = S_r^{Q_{is}} - W_{tr}\, C_i(m) + OF_r\, C_s + Q_{oga}\, C_{ga} + Q_{ob}\, C_g - Q_e\, C_e + S_r^{NS} \quad . (4.16)$$

in which

$S_r^{Q_{is}}$ = rate of salt flow associated with surface inflow waters to the subbasin

$C_i(m)$ = measured concentration of total dissolved solids associated with inflowing surface waters diverted for irrigation

C_s = salinity level associated with the overland flow and interflow components of return flow

C_{ga} = average salinity level of the groundwater within the soil solution beneath the agricultural lands

C_g = average salinity level of the groundwater within the subbasin

Q_e = rate of water diversions from surface sources for use outside the boundaries of the basin

C_e = average salinity level of water exported from the subbasin

S_r^{NS} = rate of salt flow contributed from natural sources within the basin

All other quantities are previously defined as Equation 3.32.

In Equation 4.16 the quantity $S_r^{Q_{is}}$ is estimated by summing the measured and unmeasured salt inflow rates given by Equation 4.3, 4.5, and 4.6. Salt increases within the subbasin from natural sources, S_r^{NS}, are given by Equations 4.15.

In Chapter III reference was made to both surface and subsurface components of water outflow from a subbasin (Equation 3.33). If no subsurface component of flow exists ($Q_{og} = 0$), the total rate of salt outflow as given by Equation 4.16 is carried by surface waters. Thus,

$$S_r^{Q_o} = S_r^{Q_{os}}, \quad (Q_{og} = 0) \quad . . (4.17)$$

If the termination of a subbasin exists at a gaging station under which groundwater flow occurs, the rate of salt outflow can be written as:

$$S_r^{Q_o} = S_r^{Q_{os}} + S_r^{Q_{og}} \quad . . . (4.18)$$

in which

$S_r^{Q_{os}}$ = rate of surface outflow of salt from the basin

$S_r^{Q_{og}}$ = rate of subsurface outflow of salt from the basin

The value of the surface outflow component, $S_r^{Q_{os}}$, is compared to the recorded salt outflow for verification, whereas the subsurface salt outflow, $S_r^{Q_{og}}$, is estimated by multiplying the water flow (Equation 3.34) by the groundwater concentration at the outflow. Hence, the groundwater outflow of salts can be estimated by

$$S_r^{Q_{og}} = Q_{og}\, C_{og} \quad . . . . (4.19)$$

in which

Q_{og} = rate of subsurface or groundwater outflow from the basin

C_{og} = average salinity level of the subsurface water leaving the basin at the outflow point at a particular time

As previously noted, within a groundwater basin the dissolving process may produce increased salinity concentrations in the downstream direction. Hence, what is referred to as the average groundwater salinity concentration, C_g, of a basin may be either less than or essentially equal to that occurring at the basin outlet, C_{og}. Expressed in equation form:

$$C_g \leq C_{og} \quad \ldots\ldots\ldots \quad (4.20)$$

The development of the foregoing salinity model for a typical hydrologic-salinity system has been dealt with in as general a manner as possible. Modifications may be introduced as necessary in the development of a model of a particular system. For example, in the event that there is no subsurface outflow from a subbasin, the quantity $S_r^{Q_{og}}$ is not considered. Thus, the salinity model developed in this chapter is applicable in a general sense to the simulation of any particular hydrologic-salinity flow system.

CHAPTER V
ASPECTS OF COMPUTER PROGRAMMING AND VERIFICATION OF THE HYDROLOGIC AND SALINITY FLOW SYSTEMS

In the development of a model of the hydrologic-salinity flow system, the hydrologic portion of the model was first verified for each subbasin. Simulation of the salinity flow system then was accomplished by superimposing appropriate concentrations of total dissolved solids upon the various hydrologic components of the model. However, before presenting in detail the procedures utilized in model development on the analog computer, several aspects of analog programming are discussed.

Programming Characteristics of the Analog Computer

Because they form the basis for deriving an electronic analogy to the hydrologic and salinity flow systems, several characteristics of the analog computer are presented.

The first programming consideration is the derivation of a complete set of equations which describes the system to be studied. Such equations may include mathematical functions involving algebraic summation, exponentials, logarithms, multiplication, division, trigonometric functions, differentiation, integration, and random functions. The various electronic components available on the analog computer can be interconnected with patch blocks so that each of the above mathematical expressions becomes directly analogous to voltages appearing at various points in the computer.

Voltage is used as the analogous element for both water and salt flow within the computer. By attaching a recorder in parallel with the various circuit elements, the voltage may be recorded at any point of interest within the electrical circuit, thereby indicating the magnitude of water and salt flows at the corresponding point in the physical system. Voltages corresponding to particular hydrologic and salinity inputs also can be applied at appropriate points in the computer model.

Since time is the independent variable in an analog computer program, all dependent variables are functions of time. Hence, physical variables are represented in the analog computer in terms of the dependent variable, voltage, and the independent variable, time. Since the hydrologic system variables are represented by voltage and time, it is necessary to scale the equations so that they can be solved within the computer voltage capabilities and within a realistic time period. The scaling of magnitude corresponds to scaling the dependent variable of the problem (voltage or flows) and the scaling of time corresponds to scaling the independent variable (real time).

Magnitude scaling

Correct magnitude scaling is essential for obtaining accurate results. The dynamic range of the computer used in this study was ± 100 volts, and inaccuracies result when peak voltages exceed this range. Thus all hydrologic and salinity flows were scaled in magnitude so that the normal operating range of the computer was not exceeded. The measurement units adopted for the model are as follows:

1. All hydrologic flows, such as stream flow, canal diversions, precipitation, soil moisture, and evapotranspiration, were converted to monthly volumes of water in the form of inches in depth spread over the irrigated area of a subbasin. The column height of water on a given area of agriculture land was the unit represented by voltage in the computer.

2. For the salinity model rates of salt flow were computed from concentration levels. Thus, salt flow rates carried the unit of tons per month.

3. Average monthly temperature has physical units of °F. These values were scaled to computer values on a one to one basis so that 1.0°F was equivalent to 1.0 volts. Scaled temperature voltages are important in the computation of snowmelt and evapotranspiration.

Preceding page blank

Time scaling

The selection of a suitable time scale for an analog computer program is a function of the input form of the data, the nature of the mathematical relationships, and the scope or objective of the problem. In the case of this study, the input data such as temperature and precipitation were generally available on a monthly basis. Consequently, for reasons of convenience in operating the computer, a time scale of one second computer time equivalent to one month of real time was adopted for the model. This somewhat arbitrary time scale was determined mainly by the available data. Consequently, data inputs to both the hydrologic and salinity models were quantized monthly values appearing in the computer at 1 second increments throughout the time period of interest.

Time delays

As discussed earlier, long transport delay times are required for some flows to move through the system, such as deep percolating waters and groundwater flows. These flows were simulated in the model by means of active delay networks. These networks consisted of wiring various resistors and capacitors in different combinations of series and parallel circuits. Delay periods ranged from one-half to six seconds of computer time, and from one-half to six months of real time. Although generally applicable only to surface flows, any component of water or salt which required a delay of less than 1 month was assumed to move without any time delay associated with it. The required delay setting for these resistor-capacitor networks was established by trial and error procedures during the verification studies.

Input of voltages to the computer

Both the hydrologic and salinity inputs were introduced into the simulation model in the form of voltages. These inputs can be either continuous or discrete in form. Because only monthly values were used in this study, the model inputs were discrete. The input device of the analog computer consists of time multiplexed potentiometers that are pre-set to correspond with the desired input data. A switching mechanism samples a new series of potentiometers each second. Since there are 12 monthly intervals in a year, the time taken to evaluate the model for 1 year real time was 12 seconds of computer time.

Programming the Hydrologic Flow System

The hydrologic system was modeled on the analog computer by programming the various mathematical relationships developed in Chapter III and combining them into a composite model. The model was fitted to a particular subbasin or hydrologic system by fixing certain equation constants through a verification procedure. In addition, the basic model was modified through the inclusion or exclusion of certain processes in accordance with known conditions. For example, the snowmelt process was not included in some areas where snow accumulation was known to be negligible. However, the following treatment of programming procedures includes all of the hydrologic processes and procedures outlined in Chapter III.

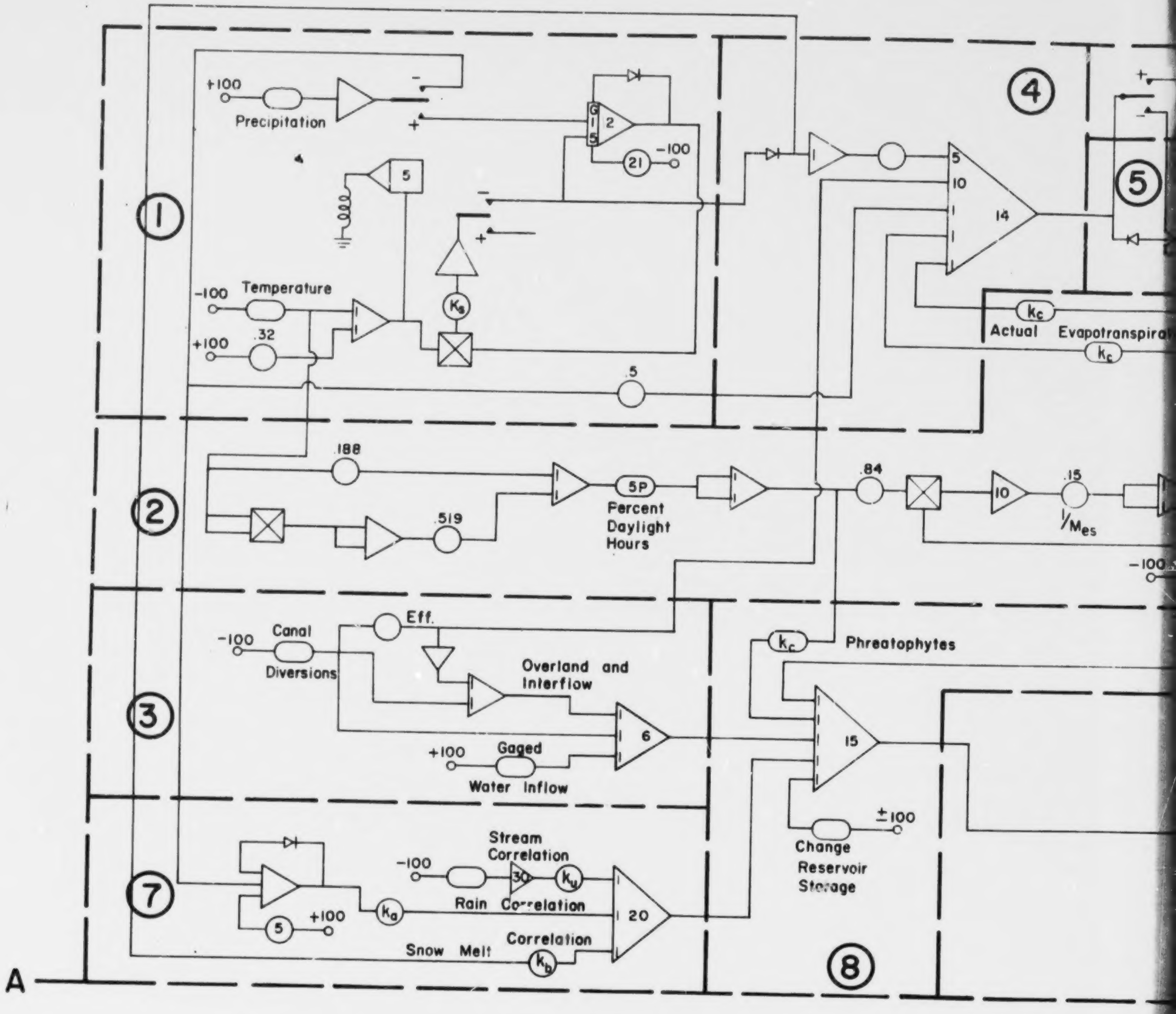
The analog wiring diagram, or computer program, which corresponds to the hydrologic system depicted in Figure 3.1 is shown by Figure 5.1. The partitions on the diagram indicate the various parts of the program in which the specific hydrologic functions or processes discussed in Chapter III are performed. The operation of the computer in simulating these processes is briefly described in the following sections. Only aspects of the program directly pertinent to the solution of the mathematical equations are discussed; no reference is made to components used for other operations, such as for scaling and limiting voltages.

Snowmelt process

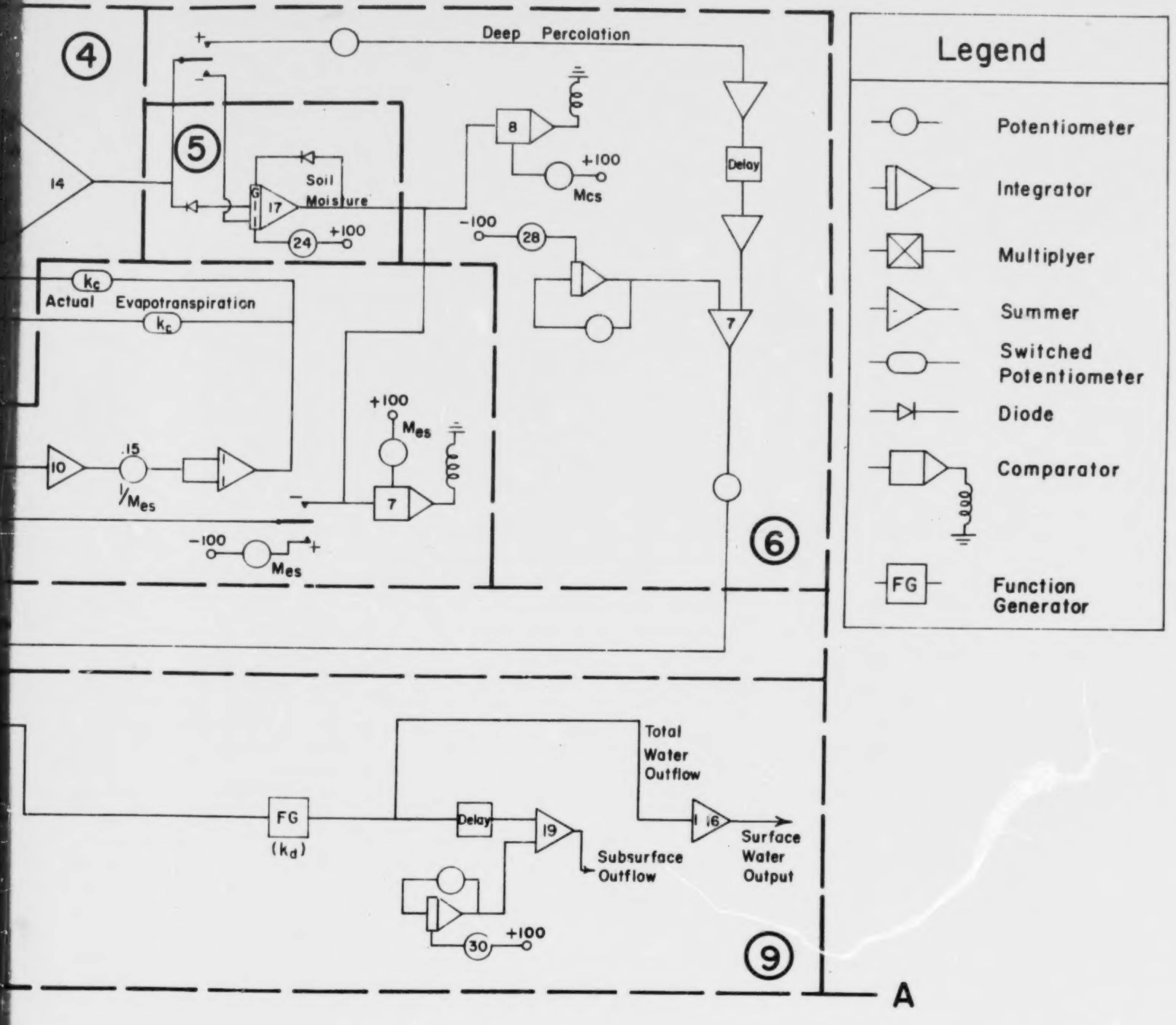
Reference is made to section one of Figure 5.1. In this section monthly precipitation and temperature values are input to the modeling program on switched potentiometers. The output from the potentiometer which is labeled 32 is a constant 32 volts representing a base temperature of 32°F. The value of each mean monthly temperature is input through a series of switched potentiometers and these values are compared to the base temperature of 32°F by the comparator labeled five. For mean temperature values below 32°F, the monthly precipitation is assumed to occur as snow and the incoming voltages are stored in integrator number two. Initial snow storage conditions at the beginning of each particular study period are input to this integrator by means of the IC potentiometer. For mean monthly temperature values greater than 32°F, comparator five switches to a different circuit and the snowmelt process is simulated. Equations 3.10 and 3.11 describe the melting process, and the rate is determined by the potentiometer k_s. At this time precipitation is assumed to occur as rain, and by means of the comparator logic (number five) is input directly to the system.

Evapotranspiration calculation

Section number two of Figure 5.1 simulates the evapotranspiration process. Reference is made to Chapter III where Equation 3.25 can be substituted into Equation 3.26 to obtain an expression written on a monthly basis as:


+100
Precipitation
G
1
5
2
21
-100
5
-100
Temperature
+100
.32
Ks
.5
1
4
5
10
14
5
kc
Actual Evapotranspirat
kc
.188
5P
Percent
Daylight
Hours
.519
2
.84
10
.15
1/Mes
-100
3
-100
Canal
Diversions
Eff.
Overland and
Interflow
6
+100
Gaged
Water Inflow
kc
Phreatophytes
15
±100
Change
Reservoir
Storage
7
-100
Stream
Correlation
30
ky
Rain Correlation
5
+100
ka
20
Snow Melt
Correlation
kb
8
A

A


④
⑤
⑥
⑨
Deep Percolation
14
Soil Moisture
17
G
24
+100
8
+100
Mcs
Delay
-100
28
7
kc
Actual Evapotranspiration
kc
+100
Mes
10
.15
1/Mes
7
-100
Mes
Total Water Outflow
FG
(kd)
Delay
19
16
Subsurface Outflow
Surface Water Output
30
+100
A
Legend
Potentiometer
Integrator
Multiplyer
Summer
Switched Potentiometer
Diode
Comparator
FG
Function Generator

42 42 A

$$ET_{cr} = k_c \left[0.0173\, t^2 - 0.314\, t \right] \frac{p}{100} \qquad (5.1)$$

in which

ET_{cr} = potential evapotranspiration rate
k_c = monthly coefficient which varies with type of crop and location
t = mean monthly temperature in degrees F
p = monthly percentage of daylight hours of the year

Evaluation of the total evapotranspiration from several crop types, in inches over the entire cropped land, is given by the expression:

$$\sum_{i=1}^{n} (ET_r)_i \frac{A_i}{A_T} = \sum_{i=1}^{n} (k_c)_i \; (0.0173\, t - 0.314) \frac{tp}{100} \qquad (5.2)$$

in which

i = i^{th} type of crop in the study area
n = total number of crops
A_i = area in acres of crop i
A_T = total cropped area in acres

Equation 5.1 is programmed in the first portion of section two. One row of switched potentiometers is set at voltages equivalent to the monthly values of the percent daylight hours, p, and the crop coefficients, k_c, are input through other rows of switched potentiometers. Although only two rows of switched potentiometers for crop coefficients are indicated by the diagram, the actual number of rows used for a particular subbasin was equal to the number of major crop varieties within the area. All other potentiometers included in this section are required to obtain the various constant values in Equation 5.1.

Equation 5.1 estimates the potential evapotranspiration rate. To estimate the actual rate as indicated by Equation 3.29, soil moisture levels within the root zone are considered through comparator seven. As long as soil moisture levels are greater than or equal to a critical value designated as M_{es} the second multiplier within this section multiplies Equation 5.1 by a factor of 1.0 and actual evapotranspiration rate equals the potential rate. However, when the available soil moisture becomes less than the limiting moisture level, M_{es}, comparator seven switches to another circuit. The multiplier then reduces the potential evapotranspiration rate by the ratio of the existing moisture level, M_s to the critical level, M_{es}, to obtain estimated rates of the actual evapotranspiration.

Diverted and return flows

Section three of Figure 5.1 is the portion of the program in which canal diversions and return flows are considered. Irrigation diversions from reservoirs, streams, and groundwater are input as voltages on a row of switched potentiometers. These values are modified by the potentiometer labeled Eff to compute the net water entering the soil surface, W_{dr} (Equation 3.14). This same rate of water flow is subtracted from the total diversion rate, W_{tr}, to compute return flow rates through surface runoff and interflow.

The unsaturated soil moisture regime

In section four of Figure 5.1 all additions to and abstractions from the soil root zone are summed at amplifier 14. For a given month inputs include diverted water entering the soil surface, W_{dr}, precipitation upon the agriculture lands, P_r, and melting snow overlying the irrigated area, W_{sr}. Actual evapotranspiration rate is an abstractive quantity and is therefore represented by a sign opposite to those of the input values. Each of the component voltages incoming to amplifier 14 is appropriately scaled.

The soil moisture storage is simulated in section 5 of Figure 5.1 by integrator 17 which both stores and discharges voltage (representing water) on a continuous basis. The integrator output function is, therefore, a continuous estimate of available soil moisture levels, $M_s(t)$, within the plant root zone. Whether voltage is added or subtracted is determined from Equation 3.17. An initial condition for the integrator is provided. Thus the soil moisture level existing at the beginning of a particular modeling period is imposed.

Deep percolation

The computation of deep percolating flow (Equations 3.30 and 3.31) is made in that portion of the Figure 5.1 which is partitioned as section six. As indicated by Equation 3.31, deep percolation is assumed nonexistent when the storage of available moisture, M_s, within the plant root zone is less than capacity, M_{cs}. This logic is implemented by comparator eight which switches to a circuit that grounds the deep percolation line, analogous to no deep percolation flow, when $M_s(t) \leq M_{cs}$. However, when the soil moisture capacity, M_{cs}, is reached, comparator eight switches to a second position and deep percolation rates are simulated by the positive voltage output of amplifier 14 (Equation 3.30).

As discussed earlier in this chapter and in Chapter III, deep percolation flows are usually delayed in the groundwater system before they appear in the basin outflow. Active delay networks (Figure 5.1) were utilized to accomplish this delay of flow. The setting required for the delay network was established during the verification studies.

Frequently, heavy applications of irrigation water occur in the late summer and early fall months. Under these conditions deep percolating waters may not appear in the basin outflow before the end of the year being modeled, and must, therefore, be considered in the subsequent model period. This requirement is met by integrator 18 with its associated initial condition setting. Hence, the total deep percolation flow rate is summed by the amplifier seven. Other potentiometers in section six are for scaling purposes.

Basin inflow

Gaged surface inflow rates are input to the model through the switched potentiometers indicated in section three of Figure 5.1. Ungaged surface inflows are estimated through correlation procedures, programmed in section seven. Amplifier number 20 has three inputs which are based on Equations 3.3 and 3.4, and when required, Equation 3.6. The ungaged surface inflow contribution from rainfall is programmed so that only the larger precipitation rates contribute to the runoff at the basin outlet. Thus, precipitation is not reflected in the basin outflow until the limiting rate on potentiometer five is exceeded. The setting required for potentiometer five was established during the verification studies.

The ungaged surface inflow contribution from snowmelt is estimated by multiplying the melting snow rate from section one by the coefficient k_b.

A measured rate of inflow to the hydrologic system, whether consisting of a single measured stream or the total gaged inflow, is placed on a row of switched potentiometers indicated on Figure 5.1 as "stream correlation." The ungaged stream inflow is then computed by multiplying the potentiometer settings by a coefficient, k_u. Similarly, subsurface ungaged inflow rates are estimated in accordance with Equation 3.6 and programmed as an input to amplifier 20.

Thus, the output of amplifier 20 is the total unmeasured inflow to the hydrologic system, and when added to the outflow from amplifier six (section three), represents total inflow to the hydrologic system (Equation 3.7). Within the basin these flows are delayed by storage functions and altered by abstractions due to diversions, and additions from return flow to form a hydrograph of basin outflow.

Basin outflow

The hydrologic outflow from a study area consists of both surface and subsurface hydrographs.

Section eight of Figure 5.1 depicts the final summation on amplifier 15 of the remaining water after it has been routed, depleted, and altered by storage through the various processes occurring within the hydrologic system. Additions to the outflow from deep percolation, measured inflows, ungaged inflows, and depletions caused by phreatophytes are summed by amplifier 15. Rates of evapotranspiration by phreatophytes are computed by applying appropriate crop coefficients, or k_c values, in Equation 5.1. However, phreatophytes are always assumed to transpire water at the potential rate. This is accomplished by multiplying the potential evapotranspiration rate, determined in section two, by the crop coefficient, k_c, selected for phreatophytes. The k_c values for phreatophytes are set on the row of switched potentiometers depicted in section eight.

Section nine of Figure 5.1 considers the portion of flow leaving the basin as subsurface flow. Subsurface outflow rates are estimated as indicated in Chapter III (Equation 3.34). The proportion of the total outflow leaving the basin as subsurface, or undergage, flow is programmed on a function generator, with the lowest percentage occurring during periods of high surface water outflow. This relationship is determined in the verification process. The computed subsurface outflow is then delayed by active delay networks as discussed earlier in this chapter. A decaying exponential function is also included in this section to enable initial conditions to be established for the subsurface outflow function.

By subtracting the estimated subsurface outflow, before delay, from the total basin outflow (output of amplifier 15) the surface portion of outflow remains (Equation 3.33), and is represented by the output of amplifier 16. This flow rate is compared to recorded outflow rates to determine the accuracy of the model. Subsurface outflow rates are given at the output of amplifier 19.

Programming the Combined Hydrologic-Salinity Flow Systems

Programming the hydrologic and salinity flow systems is accomplished by superimposing the salinity (total dissolved solids) flow system upon the hydrologic system. In the physical system this objective is accomplished by measuring salt concentrations within the flowing water and then converting these values to mass rates of salt flow. The two systems are then related through the mass of salt transported by a rate of water flow. As with the hydrologic system, the continuity of mass principle is the underlying concept upon which the salinity system is developed (Equation 2.1).

The salinity flow system was programmed on the electronic analog computer through the concepts and equations of Chapter IV. The relationships developed in this chapter were not always required in the model of a particular subbasin. However, to illustrate programming techniques, all salinity equations are discussed in this chapter.

The total salt outflow from a subbasin was expressed in Chapter IV as Equations 4.16 and 4.18. Note that the discharge function for salt flow from a subbasin is estimated by associating an appropriate salinity concentration with a particular hydrologic flow rate. Thus, the salinity dimension was added to the computer model of the hydrologic system (Figure 5.1) by multiplying the various water flow rates by their associated salinity concentration levels. The analog computer diagram of Figure 5.2 includes the salinity dimension. This diagram also corresponds to the salinity flow system depicted in Figure 4.1 and expressed in Equations 4.8 and 4.16. Careful comparison indicates that Figure 5.1 and Figure 5.2 above section line A-A are identical. This similarity is also illustrated by Figures 3.1 and 4.1. Each partitioned section above line A-A in Figure 5.2 is identical to corresponding partitioned sections in Figure 5.1, and programming procedures for this part of the hydro-salinity model will not be repeated.

All voltages below line A-A (section 10) of Figure 5.2 are analogous to salt flow. Salinity concentrations are input to the program through appropriate potentiometer settings. Each of the salinity flow components in this section are discussed briefly as follows:

1. The measured water inflow rates to the subbasin, less irrigation diversions, are given at the output of amplifier six in section three. However, salinity records do not exist for some of the measured water inflow streams. The measured water quantity inflow rates are described in Equations 4.3 and 4.4. The unmeasured water inflows to the subbasin are totaled by amplifier 20 of section seven. A potentiometer separates the measured water inflow into two portions, depending upon the availability of water quality measurements. The voltage at the output of amplifier 21 represents the total ungaged mass rate of salt inflow associated with both measured and ungaged water which lack salinity concentrations. Multiplication of this voltage by the estimated salinity concentration parameters, $C_{is}^{j}(u)$ and $C_{is}(u)$, provides an estimate of the ungaged salt inflow rate in accordance with Equations 4.3 and 4.4. These salinity concentration values are input to the program by switched potentiometers. When groundwater inflow occurs within a subbasin (Equation 4.7), this component is multiplied by the groundwater salinity level within the subbasin, $C_g(u)$.

2. The mass rate of salt inflow from measured inputs is computed from Equation 4.3 by multiplying the water flow rate term by appropriately measured salinity concentrations, $C_i(m)$. These values are set upon a row of switched potentiometers.

3. The computation of the natural contribution to the salt load is made by programming Equation 4.15. The groundwater salinity concentration, C_g, is multiplied by the portion of surface flow allowed to interchange with the groundwater basin.

4. To simulate salt flow associated with irrigated agriculture, the deep percolating stream of water, G_r, is multiplied by the agricultural groundwater concentration, C_{ga}. Thus, the rate of salt movement associated with the groundwater component of the irrigation return flows is modeled in accordance with Equations 4.12 and 4.13. The other salt load produced by the agricultural system is that associated with the surface runoff and interflow components of the return flow (Equation 4.11). These flows are returned to the main stream channel at amplifier six (section 3 of Figure 5.2). To estimate the rate of salt movement carried by the returning surface runoff and interflow water, these flows are multiplied by a concentration level, C_s, in accordance with Equation 4.11 (section 10 of Figure 5.2). The value of C_s is estimated during the model verification studies.

5. The total salt outflow rate from the subbasin is given at the output of amplifer 18. The five inputs to this amplifier include ungaged salt flow (surface), measured salt flow, irrigation return flows (surface), salt flow from natural sources, and salt flow from the groundwater basin resulting from deep percolating irrigation water and subsurface inflows to the area. The output voltage of amplifier 18 corresponds to the rate of salt flow indicated by Equation 4.16. Since salt is non-degradable, the subbasin outflow function reflects the influences upon the input function of storage changes and various inbasin contributions.

6. At the extreme right of section 10 (Figure 5.2) both the surface and subsurface components of salt outflow are programmed in accordance with Equations 4.18 and 4.19. The dissolved solids concentration of the groundwater at the outflow point, C_{og}, is multiplied by the rate of subsurface water outflow. The surface component of salt outflow is computed by subtracting the

subsurface component from the total subbasin outflow rate (Equation 4.18). Computed salt surface outflow values then can be compared with recorded values to calibrate and test the salinity flow model.

Verification of the Hydrologic and Salinity Models

In Chapters III and IV some general mathematical relationships are presented which describe both the hydrologic and salinity flow systems. These relationships are then synthesized into a general model of the hydro-salinity system in accordance with Figure 5.2. This model is sufficiently general to be applied to any geographic area. Application of the model to a particular subbasin is achieved by evaluating and testing model parameters for the subbasin. This procedure is termed model verification.

The model is verified for a particular subbasin by inputing measured or estimated input values pertaining to the hydrologic and salinity systems, and then comparing the predicted outputs from the analog computer with the corresponding measured outflows from the prototype. Model parameters are adjusted within specific ranges until close agreement is reached between predicted and recorded outflows for a given period. For models based on a monthly time increment it is usual practice to operate the model over a period of at least two years (24 successive months). Initial or antecedent conditions for the second year, such as accumulated soil moisture and groundwater flow rate, are those which existed in the model at the end of the last month of the first year. Where possible years are selected for characterizing the model input data which represents a wide range of hydrologic conditions. Calibration of the model for a particular subbasin is complete when all parameters within the system are established so that measured and computed output values are in close agreement. Usually, the procedure is repeated several times with slight alterations each succeeding time to obtain a model which predicts both years with the desired accuracy. Finally, the model calibration is tested by inputting data from the prototype which was not used in the calibration procedure. These two steps of calibration and testing then represent model verification for a specific subbasin.

Those parameters in the hydro-salinity model which require evaluation and testing in the verification process include:

1. Constants in the precipitation and snowmelt relationships, threshold value at which the precipitation correlation is initiated, and coefficients relating the portion of ungaged inflow attributable to precipitation and snowmelt.
2. Coefficients in various correlations relating measured inflows to ungaged inputs from tributary streams, and subsurface inflows and outflows.
3. Irrigation and application efficiencies.
4. Soil moisture characteristics, including M_{cs}, M_{es}, and initial conditions.
5. Rates of decay on initial conditions for groundwater delays as well as the groundwater delay time itself.
6. Increase in salinity level in surface return flows from agricultural lands.
7. Groundwater salinity concentrations at various points within the system.

Values for the basin parameters discussed above are set on potentiometers on the analog computer (Figures 5.1 and 5.2) and adjusted during the model verification procedure.

The degree to which the hydrologic and salinity flow systems within a prototype can be defined depends upon both the temporal and spatial variations within the systems and the adequacy of the sampling or data collection network in terms of these two dimensions (Riley et al., 1969). Thus, the accuracy with which the model simulates the prototype is highly dependent upon the degree to which the flow systems can be defined through available field data. Frequently it is necessary to augment existing data by statistical correlation procedures conducted either through independent analyses or as a part of the model verification procedure.

The equations presented in Chapters III and IV were synthesized into a general computer model of the hydro-salinity flow system. This model was then verified for each of the designated subbasins within the Upper Colorado River drainage. In the following chapter the verification procedure is illustrated through application of the model to a specific hydrologic subbasin.

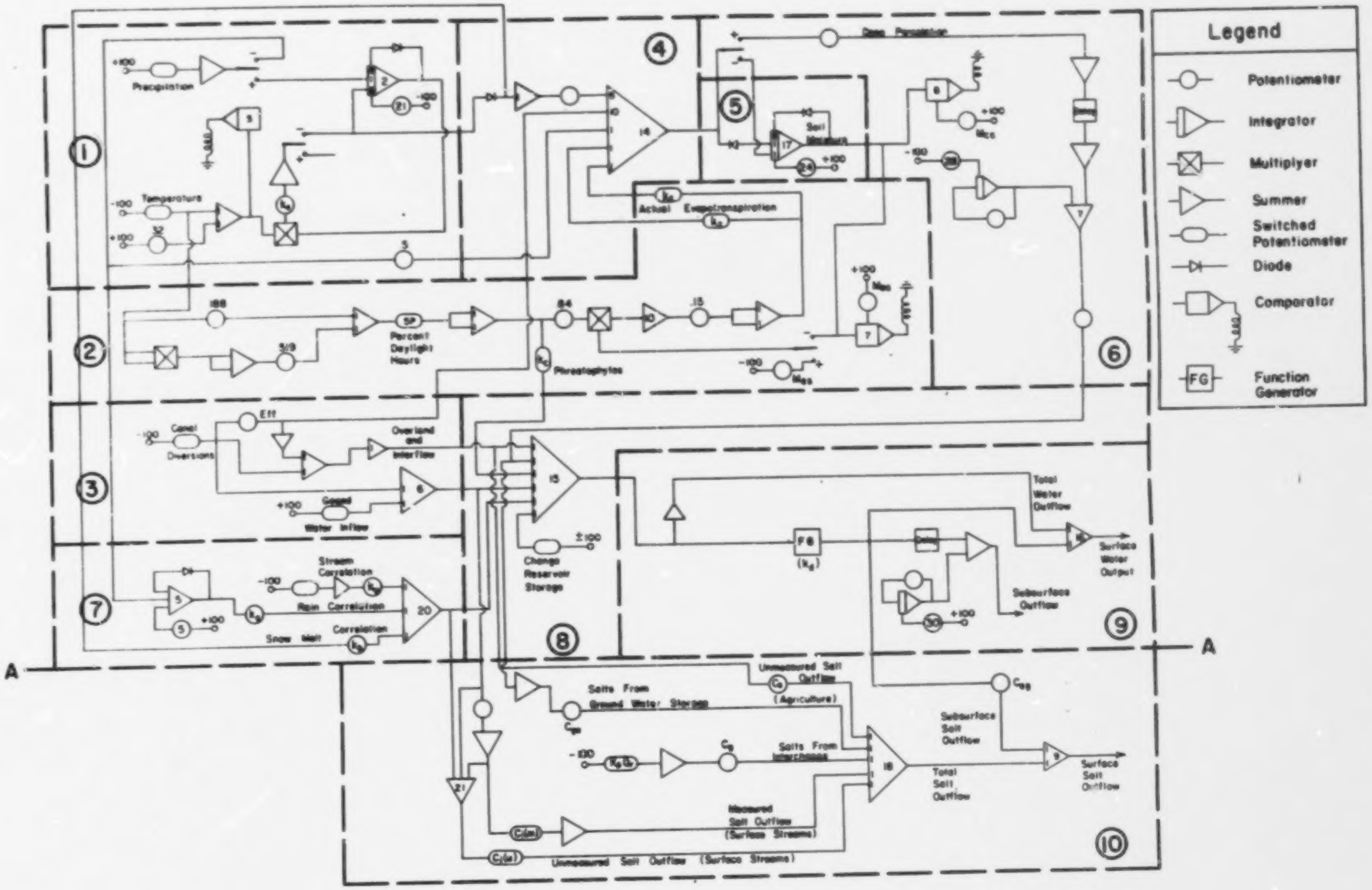

Legend
Potentiometer
Integrator
Multiplyer
Summer
Switched Potentiometer
Diode
Comparator
FG
Function Generator
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
A
A
+100
Precipitation
-100
21
Temperature
-100
+100
32
5
188
319
SP
Percent Daylight Hours
84
.15
Phreatophytes
Actual Evapotranspiration
14
Soil Moisture
17
24
+100
Deep Percolation
+100
-100
Canal Diversions
Eff
Overland and Interflow
6
+100
Gaged Water Inflow
-100
Stream Correlation
Rain Correlation
Snow Melt Correlation
+100
20
15
±100
Change Reservoir Storage
FG
(k_g)
Delay
Total Water Outflow
Surface Water Output
Subsurface Outflow
+100
Unmeasured Salt Outflow
(Agriculture)
Salts From Ground Water Storage
C_{gs}
-100
C_g
Salts From Interchange
18
Total Salt Outflow
Subsurface Salt Outflow
C_{ss}
9
Surface Salt Outflow
Measured Salt Outflow (Surface Streams)
Unmeasured Salt Outflow (Surface Streams)
21

Figure 5.2. Analog computer wiring diagram for the hydrologic and salinity flow system.

CHAPTER VI

APPLICATION OF THE COMPUTER MODEL TO THE HYDROLOGIC-SALINITY FLOW SYSTEM OF THE UPPER COLORADO RIVER BASIN

Verification of a simulation model is accomplished through a calibration and testing procedure using actual data from a prototype system. Model parameters within the equations used to describe the various hydrologic and salinity processes are adjusted until known output functions are accurately duplicated. For this reason, complete and reliable data are essential for an accurate and thorough evaluation of model relationships and concepts.

Description of Basin

A portion of the information contained in the following section describing this basin was abstracted from Iorns, Hembree, and Oakland (1965). Because of the comprehensive nature of their report, it was utilized where possible in this study.

Location

The Upper Colorado River basin (Figure 6.1) consists of approximately 110,000 square miles in southwestern Wyoming, eastern Utah, western Colorado, northwestern New Mexico, and northeastern Arizona. The name Colorado originates from the early Spanish explorers who so named it because of its "ruddy" color that results from the large sediment loads transported by the river. The basin extends from a latitude of $35^{\circ}34'$ north to $43^{\circ}27'$ north, or a distance of about 550 miles, and from longitude $105^{\circ}38'$ west to $112^{\circ}19'$ west, or a distance of 350 miles. The basin is bounded on the west by the crests of the Paria and Aquarius Plateaus, the Wasatch Range, and Wyoming Range where it intersects with the Continental Divide at the north end of the Wind River Range in Wyoming. Following the Continental Divide some 1,000 miles southward, the basin almost reaches Gallup, New Mexico, before continuing westward along the crest of the Chuska Mountains, Black Mesa, and Kaibito Plateau, terminating at Lee Ferry in Arizona. Lee Ferry, an arbitrary point dividing the Upper Colorado River basin from the Lower Colorado River basin, has been designated as the Colorado River compact point. It is located on the main stem of the Colorado River 1 mile below the mouth of the Paria River, which has led to confusion with an old ferry site called Lee Ferry, which lies 1 mile above the mouth of the Paria River.

Population

Much of the Upper Colorado River basin is uninhabited. The 1960 census indicated a population of approximately 335,600. This amounts to a population density of about 3.25 people per square mile within the basin. The approximate distribution as given by Iorns et al. (1965) is Colorado, 170,000; Utah, 69,000; New Mexico, 59,000; Wyoming, 33,100; and Arizona, 4,500. This same reference lists the five largest communities and their approximate populations as: Farmington, New Mexico, 24,000; Grand Junction, Colorado, 19,000; Durango, Colorado, 11,000; Rock Springs, Wyoming, 11,000; and Price, Utah, 7,000. Of these five communities, only Rock Springs, Wyoming, is not on a major tributary of the basin. Rock Springs also is one of the few towns not fully dependent upon farming and ranching to support its economy. Instead, it depends upon railroad, mining, and oil industries. In general, the economy of communities within the basin depends upon agricultural enterprises that include some stock raising. The result is a reasonably stable economy and population growth (Iorns et al., 1965).

River development

Agriculture has long been practiced in the Upper Colorado River basin, but prior to 1900 irrigated production was confined to areas around the tributaries and headwaters because of the wild and untamed nature of the main stem. The Federal Reclamation Act, passed in 1902, initiated more intensive agricultural development. Subsequent projects of the U.S. Bureau of Reclamation (USBR) have brought irrigation water to large areas within the basin. The first USBR project in the Upper basin was initiated in 1902 along the Uncompaghre River in Colorado. Since that date many additional projects have been built, and numerous others are still pending.

In the 1950's plans were developed for the construction of storage dams on the river. Most of the dams were scheduled to be completed during the 1960's. Glen Canyon Dam, which creates Lake Powell, is the largest of the group with a total height of 700 feet, and a capacity of 20,876,000 acre-feet. Other large dams include Navajo, Fontanelle, Flaming Gorge, Blue Mesa, and Morrow Point. The reservoirs behind these six dams have an aggregate usable capacity of about 27 million acre-

Preceding page blank

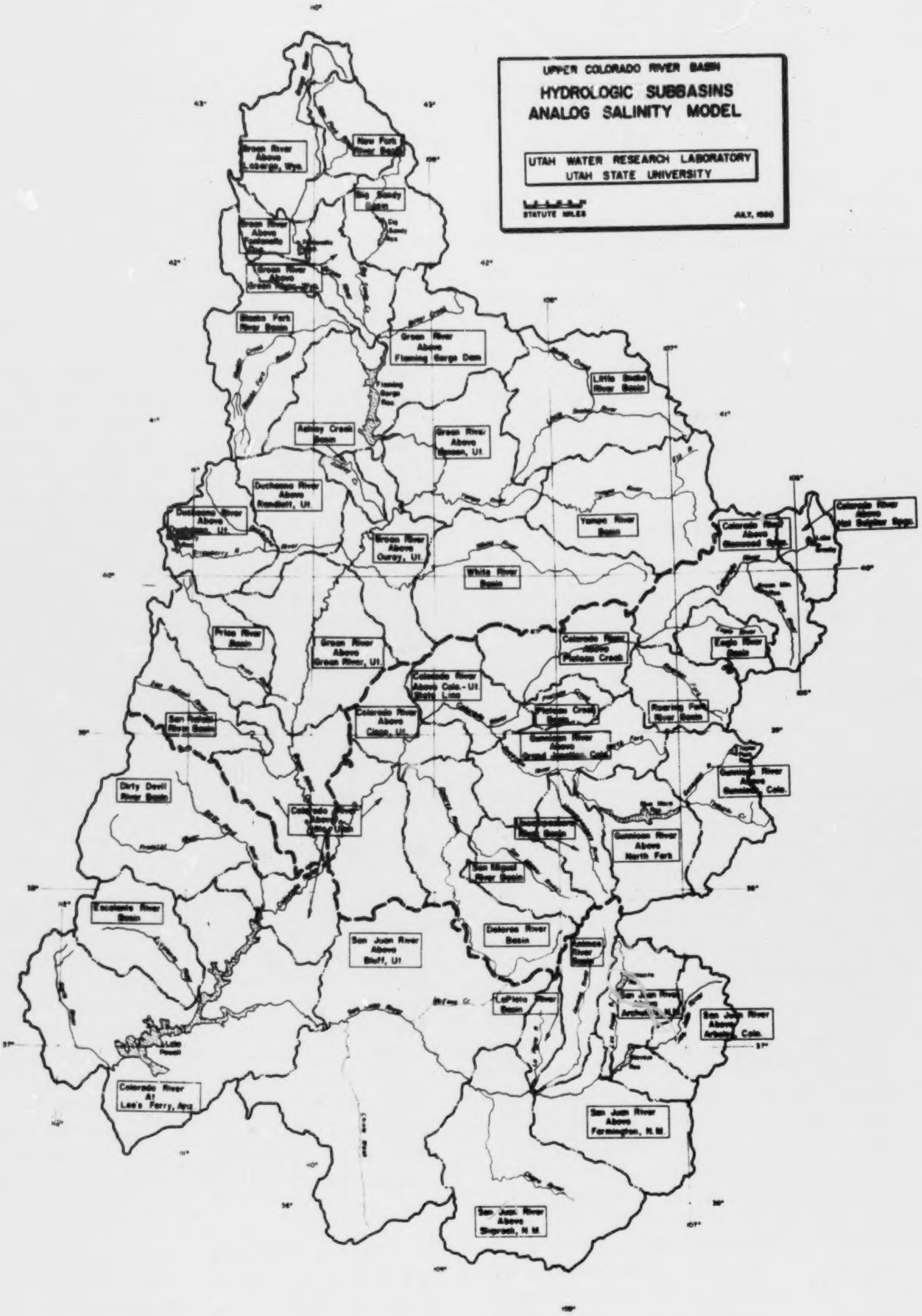

UPPER COLORADO RIVER BASIN
HYDROLOGIC SUBBASINS
ANALOG SALINITY MODEL
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
JULY, 1980
Green River Above Labarge, Wyo.
New Fork River Basin
Big Sandy Basin
Blacks Fork River Basin
Green River Above Flaming Gorge Dam
Flaming Gorge Res.
Little Snake River Basin
Ashley Creek Basin
Green River Above Jensen, Ut.
Duchesne River Above Randlett, Ut.
Yampa River Basin
Green River Above Ouray, Ut.
White River Basin
Colorado River Above Glenwood Spgs.
Colorado River Above Hot Sulphur Spgs.
Price River Basin
Green River Above Green River, Ut.
Colorado River Above Plateau Creek
Eagle River Basin
Colorado River Above Colo.-Ut. State Line
Colorado River Above Cisco, Ut.
Roaring Fork River Basin
Gunnison River Above Grand Junction, Colo.
Dirty Devil River Basin
Gunnison River Above North Fork
San Miguel River Basin
Escalante River Basin
San Juan River Above Bluff, Ut.
Dolores River Basin
Animas River Basin
LaPlata River Basin
San Juan River Above Arboles, Colo.
Lake Powell
Colorado River At Lee's Ferry, Ariz.
San Juan River Above Farmington, N.M.
San Juan River Above Shiprock, N.M.

Figure 6.1. Upper Colorado River basin showing main tributary divisions and hydrologic subbasins.

feet or about twice the average annual flow of the Colorado River at Lee Ferry.

Topography

As indicated by Iorns et al. (1965), the mountains and plateaus that form the Upper basin as well as mountain ranges within the interior of the basin are "uplifted earth masses deeply dissected by erosion, by glaciation, and by weathering." The basin interior consists of several mountain ranges, plateaus, mesas, and broad basins that vary from gently rolling to deeply eroded.

During the Paleozoic and Mesozoic eras, the basin topography was considerably more uniform than at present and was the retreat of great inland seas. The sedimentary deposits which accumulated during that time are the major source of the total dissolved solids now carried by the waters of the basin. Toward the end of the Mesozoic and during the early Cenozoic eras, earth movements created the Rocky Mountains and other mountain ranges within the basin. Continuous erosion since then has produced the present topography.

The northern portion of the basin in Wyoming and Colorado is a mountainous plateau 5,000 to 8,000 feet in elevation, that includes broad rolling valleys and high intersecting mountain ranges with many peaks exceeding 14,000 feet in elevation. Numerous mountain lakes exist in these areas. In the southern portion of the basin, broad, alluvial valleys and rolling plateaus are interspersed with additional mountain ranges. The main stem river and major tributary streams generally flow through deep mountain canyons. The Glen Canyon section of the main stem and tributaries lies almost entirely in deep canyons. Hence, the southern part of the basin, although still reaching elevations of 7,000 to 8,000 feet in mountainous areas, is generally at elevations which vary between 3,000 and 4,000 feet.

Climate

The Upper Colorado River basin is subject to climatic extremes ranging from year-round snow cover and heavy precipitation in the Rockies to desert conditions in the southern part of the basin. Differences in altitude, latitude, and high mountain range configuration contribute to these variations. Very erratic storm patterns are attributable to deflection and obstruction by the mountain ranges. Moist Pacific air masses bring most of the precipitation during the fall and winter, whereas spring and summer storms originate essentially in the Gulf of Mexico. In winter precipitation occurs mostly as snow in the north and rain in the south. During the summer, precipitation throughout the entire basin is characterized by localized, infrequent cloud burst activity. Much of the basin is arid, with annual rainfall in the south averaging as low as 2.5 inches. However, in the high mountains annual precipitation ranges from 40 to 60 inches.

The northern portion of the basin has short, warm summers with long, cold winters. The southern part has long, hot summers with few storms, and winters with virtually no freezing temperatures. For the entire basin temperature extremes range from 50°F below zero to 130°F above zero.

Vegetation

The higher elevations of the basin are covered with forests of pine, fir, spruce, and aspens, with occasional small glades and mountain meadows. Vegetation at the intermediate elevations, or the mesa and plateau regions, is mainly pinon and juniper trees with scattered areas of scrub oak, mountain mahogany, rabbit brush, sagebrush, and similar plants. Usually the streams are lined with phreatophytic growth consisting of cottonwoods, willows, grease woods, salt cedar, and grass. The low elevations support essentially desert growth, consisting of desert shrubs, yucca plants, and saguaro cacti with occasional groupings of cottonwoods and willows adjacent to stream channels.

Geology

Rocks within the Upper basin range from those in the oldest known geological period (Archean Era) to recent alluvial deposits, including igneous, sedimentary, and metamorphic types. The high mountain ranges are composed of granites, schists, gneisses, lava, and sharply folded sedimentary rocks of limestone, sandstone, and shale. Erosion, deposition, and earth movement are the phenomena responsible for the geographic location of the various deposits. By contrast, the plateau country in Wyoming, Utah, and Arizona is composed primarily of horizontal strata of sedimentary rocks that have been severely eroded to form the narrow deep canyons of the Colorado River and its tributaries.

The geology of the Upper Colorado River basin is the dominant factor in the occurrence, behavior, and chemical qualities of the water resources of the basin. Amounts of dissolved solids within the water increase downstream from the headwaters in relation to the geologic character of the intervening terrain. In the mountain area a close relationship exists between the groundwater in the consolidated rocks and alluvium and surface water. All snow and rain ultimately reach the surface stream system by way of springs, seeps, or through the alluvium along stream beds. Iorns et al. (1965) indicate that as the stream elevation rises and falls, water alternately moves from the stream into the alluvium and back again. Hence, an almost continuous interchange or recirculation of water exists between groundwater and surface water. Through this process the subsurface water, which reacts with the underlying geologic formation and valley bottom alluvium, imparts a distinctive chemical characteristic (generally a considerably increased level of total dissolved solids) to surface waters. The geologic formations most responsible for salinity levels in the natural runoff consist of evaporites of the Paleozoic Era, shales of the Aetaceous Era, and gypsum and salt of the Tertiary Era.

Soils

The soils of the Upper basin closely resemble their parent geologic formations. Soils of the Brown and Chestnut Great Soil Group have developed in areas of high rainfall, whereas most of the soils in the remainder of the basin fall into the Gray-Desert Great Soil Group (U.S. Bureau of Reclamation, 1967). This same reference indicates extensive areas of Eolian deposits (uniformly textured soils desirable for agricultural use) in parts of the basin, principally in southwestern Colorado. Saline and alkali (sodic) soils occur throughout the basin.

Much of the basin is characterized by residual soils that are usually shallow in depth and overlie shale and sandstone formations. Many of the shale formations are saline, containing gypsum and other chloride and sulfate salts. The alluvia are widely scattered and extremely variable, occurring in fans, terraces, and outwash plains. The alluvial materials either are original or have been transported and mixed extremely well (U.S. Bureau of Reclamation, 1967). Most of the agricultural enterprises are found on the well-mixed alluvia.

Compacts and treaties

The most significant and controversial compact that has been negotiated for the entire Colorado River basin involves Colorado, New Mexico, Utah, and Wyoming, as the Upper basin states, and Arizona, California, and Nevada as the Lower basin states. The compact was signed in 1922 by a commissioner of each of the seven states and by a representative of the United States Government. The effective date was 1929, and all of the states involved except Arizona had ratified the compact by that year. The compact named Lee Ferry as the dividing point between the Upper and Lower basins. In essence, the compact allows the Upper and Lower basins each a total of 7,500,000 acre-feet annually in perpetuity. In addition, the Lower basin is allowed to increase its beneficial consumptive use by 1 million acre-feet annually. Another clause stipulates that water use in the upper division is not to deplete the river flow at Lee Ferry below an aggregate of 75 million acre-feet in any ten consecutive years. Further mention is made of obligations to Mexico, possible exportation, and agreements within either of the two portions of the basin.

Another treaty affecting the basin is the Mexican Treaty, signed in 1944, which guarantees an annual delivery to Mexico of 1 1/2 million acre-feet of Colorado River water. The quality of the water for this allocation is now coming under scrutiny.

A compact among the Upper basin states allocates to each state a percentage of the annual share allotted to the Upper basin states. No mention is made of water quality. This so-called Upper Colorado River Basin Compact was signed in 1948. To Arizona is allotted 50,000 acre-feet per year with the remaining water apportioned as follows:

1. State of Colorado––51.75 percent
2. State of New Mexico––11.25 percent
3. State of Utah––23.0 percent
4. State of Wyoming––14.0 percent

Water quality is now receiving attention from those planning development, and it is a factor in proposed activities by basin developers.

Hydrology

The Colorado River itself originates in the high peaks of the Rocky Mountains, and travels some 650 miles before reaching Lee Ferry. The Green River, the largest tributary, originates in the southwestern part of Wyoming in the Wind River Range, traveling southward some 730 miles to its junction with the Colorado River about 60 miles south of the town of Green River, Utah. The Green River drains 70 percent more area than does the Colorado River above their junction. A major tributary to the Green River is the Yampa River, which drains northwestern Colorado.

The second largest tributary to the Colorado River is the San Juan River, which begins on the western slopes of the Continental Divide in the southeastern portion of the basin and flows westward to meet the Colorado River about 75 miles west of Bluff, Utah. The other major tributary to the Colorado River is the Gunnison River, which drains the northern slope of the San Juan Range and part of the western slope of the Rocky Mountains. Because almost 50 percent of the Upper Colorado River basin receives less than 12 inches average annual precipitation, most of the interior tributary streams are ephemeral, with water flowing in them only after infrequent storms.

The Upper basin divides naturally into essentially three major drainage systems, referred to here as "divisions." These divisions are designated the Grand, the Green, and the San Juan. The Grand division consists of the drainage area of the Colorado River above its junction with the Green River. The entire Green River drainage comprises the Green division. The San Juan division is the drainage area of the Upper basin between the junction of the Green River with the Colorado River and Lee Ferry, Arizona (Figure 6.1). These three divisions follow the representations used by Iorns et al. (1964 and 1965) and facilitate concise presentation of information about an extensive and diverse area.

The mean annual discharge patterns of the Green, Grand, and San Juan divisions are shown in Figures 6.2, 6.3, and 6.4, respectively. The data presented were either recorded or estimated through correlation procedures for each of the three divisions. The flow diagrams in Figures 6.2, 6.3, and 6.4 have been adjusted to reflect the effects of 1960 physical conditions within the basin for the entire 1931-1960 time period.

Flows of the Green River are presently (1969) regulated by the Fontenelle and Flaming Gorge dams. The Navajo dam provides regulation of the San Juan River. The Blue Mesa dam provides some storage on the Gunnison River and additional storage will be provided by the remainder of the Curecanti Dams of the U.S. Bureau of Reclamation. On the main stem of the Colorado River above Lee Ferry, regulation of almost all flows leaving the Upper basin is provided by the Glen Canyon reservoir. Although natural river flows fluctuate widely, these variations are minimized by the reservoirs.

Water quality

In several respects the average quality of the waters of the Colorado River is vastly superior to that of many streams in the eastern United States. However, the limited quantity of water in the Colorado River, with respect to present and future demands, necessitates an increasingly careful attention to quality. At present the most crucial water quality parameter within Upper basin is the total dissolved solids content of the water.

As mentioned in the preceding section, most of the water within the basin originates on the mountain ranges and high plateaus. The exposed rocks in the mountains are relatively resistant to the solvent action of water, so that the dissolved solids content of runoff from these areas tends to be low. The rocks that underlie much of the lower portion of the basin, however, are relatively soluble and contribute significant quantities of dissolved solids to the drainage waters.

Figures similar to those indicating the mean annual discharge pattern of water have been prepared for total dissolved solids concentrations on a long-term basis for each of the three divisions (Figures 6.5, 6.6, and 6.7). At the headwaters of the Green River itself, originating within the Wind River Range, the average concentration of total dissolved solids is about 20 to 50 ppm. The other major sources of water within this division originate in the Uintah Mountains, again with total dissolved solids concentrations of approximately 20 to 50 ppm, and on the western slopes of the Rocky Mountains, where the few available water quality measurements indicate salinity levels of the same magnitude. At Green River, Utah, however, the water has reached a concentration of 490 ppm.

The headwaters of the main stems of the Colorado and of the Gunnison Rivers have concentrations of total dissolved solids averaging from 50 to 100 ppm. These waters reach an average salinity level of 580 ppm at their confluence at Grand Junction, Colorado. At the downstream end of the division salinity levels average about 730 ppm.

For the San Juan division, average salinity levels in the headwaters range from 30 to 100 ppm, reach concentrations of 300 ppm at Farmington, and enter the main stem of the Colorado with a total dissolved solids content of 500 ppm.

Water leaving the Upper Colorado River basin at Lee Ferry contains an average total dissolved solids concentration of about 585 ppm. As has been indicated, the chemical quality of waters within the Upper basin varies considerably in both the spatial and temperal dimensions. In general, temporal variations are inversely related to streamflow, with the lowest salinity concentrations occurring during high flow periods, and the highest salinity concentrations occurring at times of low flow. The range of this variation is small in headwater streams and relatively large in main rivers. Iorns et al. (1965) describe the fluctuations in total dissolved solids concentrations in terms of a "coefficient of variation" that is obtained from the daily records of several stations within each division. These coefficients of variation, derived by comparing weighted-average concentration of dissolved solids to water discharge, can then be used to estimate the dissolved solids concentration at sites where continuous records of chemical quality are of short duration or where such data are obtained infrequently.

Although the Grand division of the Upper basin has the smallest drainage area, it contributes more water and more dissolved solids than either of the other two divisions. Iorns et al. (1965) estimate that about 48 percent of the dissolved solids recorded at Lee Ferry, Arizona, originate in the Grand division, 33 percent from the Green division, and 19 percent from the San Juan division. In the latter division, the San Juan River itself contributes about 11 percent of the 19 percent total.

Combination of the surface water quality data (Figures 6.5, 6.6, and 6.7) with the water flow data (Figures 6.2, 6.3, and 6.4) produces average salinity flow diagrams for the Green, Grand, and San Juan divisions, respectively (Figures 6.8, 6.9, and 6.10). Data are presented on a mean weight basis, the units being tons per year divided by a reduction factor of 1000. Hence, the mean annual weight of dissolved solids leaving the Upper Colorado River basin as gaged at Lee Ferry is estimated to be 8,880,000 tons. Of this total it is estimated that the Green division contributes about 2,650,000 tons, the Grand division about 4,125,000 tons, and the San Juan division the remaining 2,105,000 tons with about 1,030,000 coming from the San Juan River system itself. Within the Green division, at the confluence of the Green and Yampa Rivers, average annual water discharge

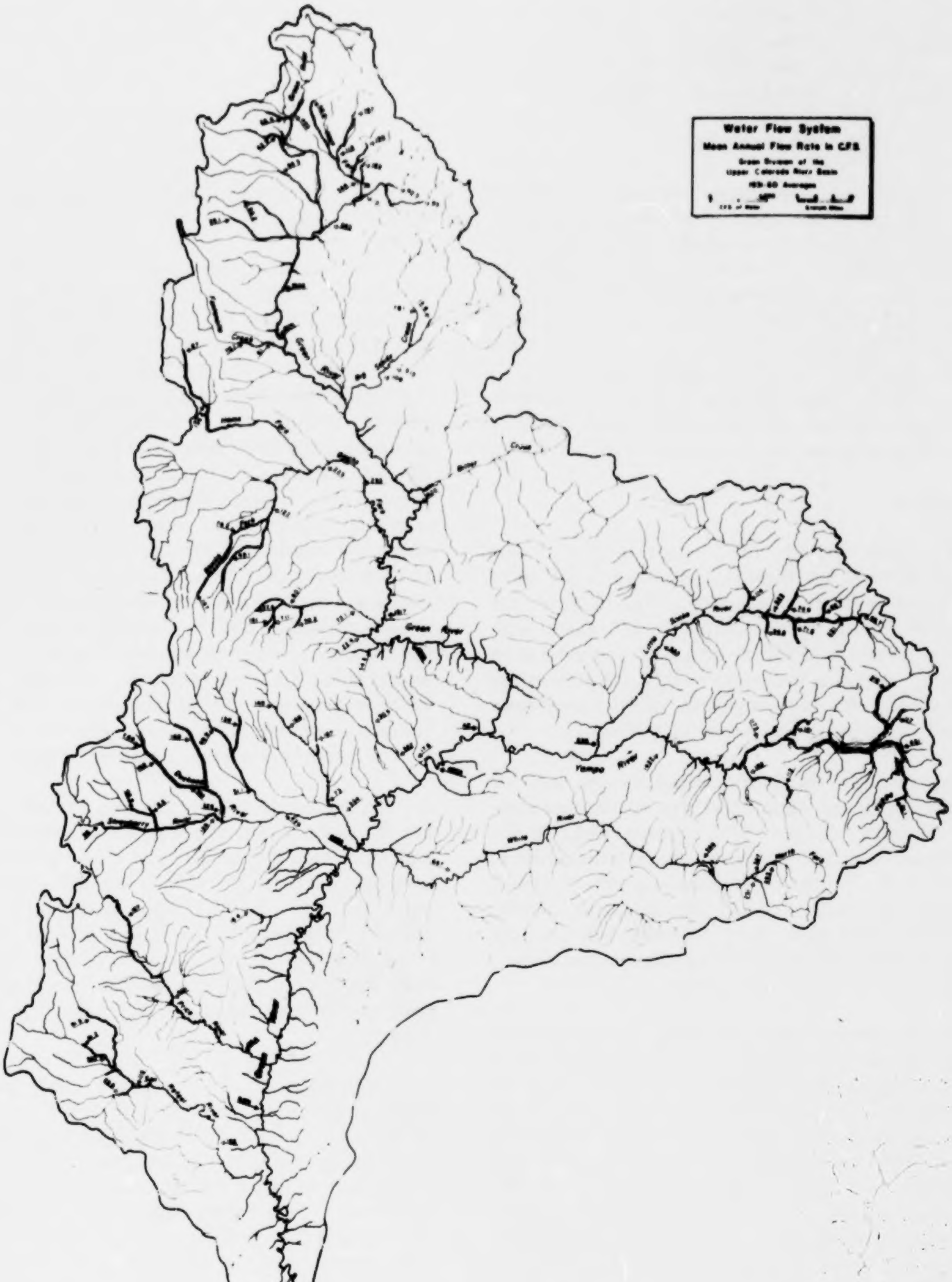

Water Flow System
Mean Annual Flow Rate in CFS
Green Division of the
Upper Colorado River Basin
Averages
Green River
Yampa River
White River

Figure 6.2. Mean annual water flow rates, Green division.

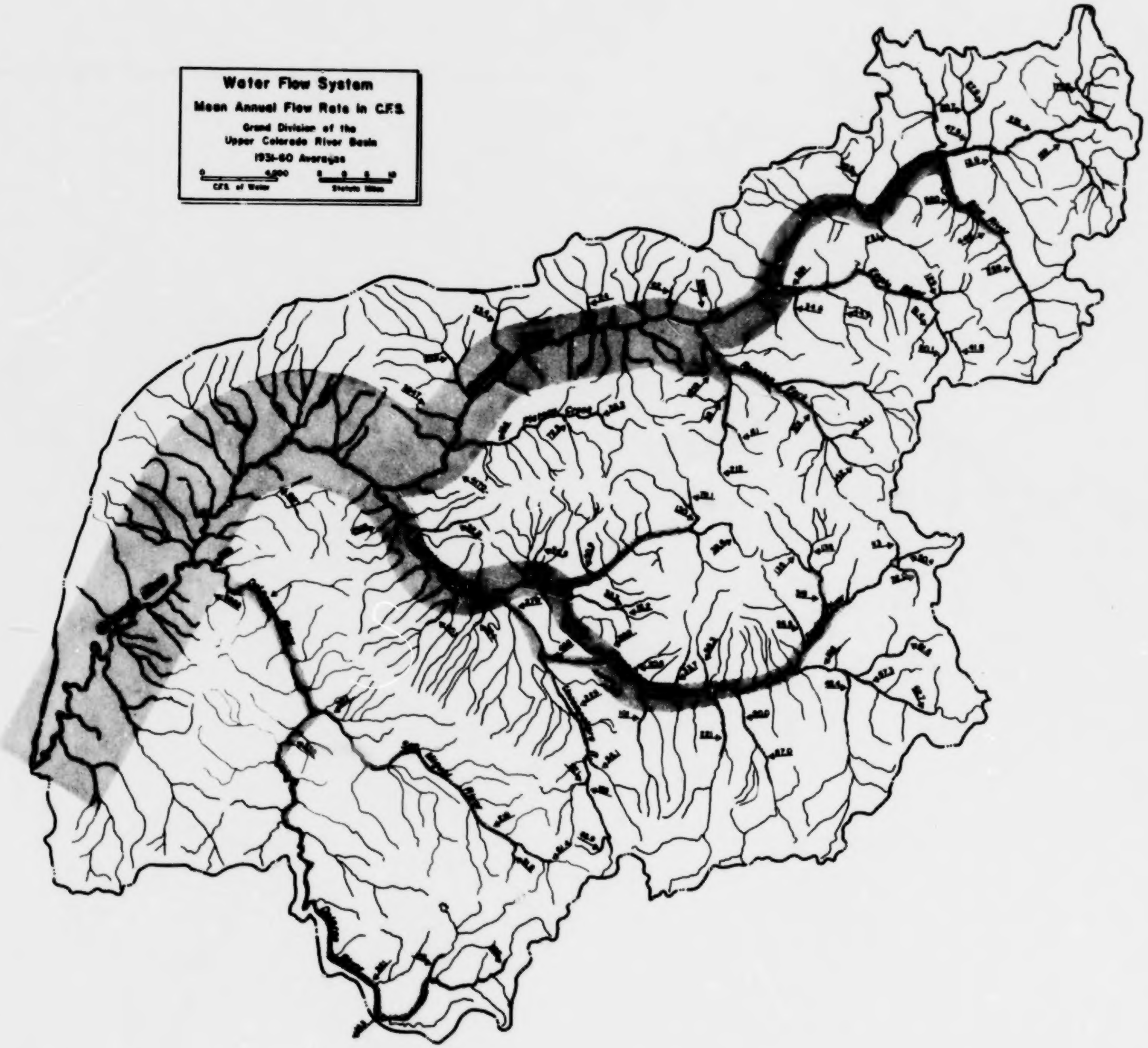

Water Flow System
Mean Annual Flow Rate in C.F.S.
Grand Division of the
Upper Colorado River Basin
1931-60 Averages
0
4,000
C.F.S. of Water
0
10
Statute Miles

Figure 6.3. Mean annual water flow rates, Grand division.

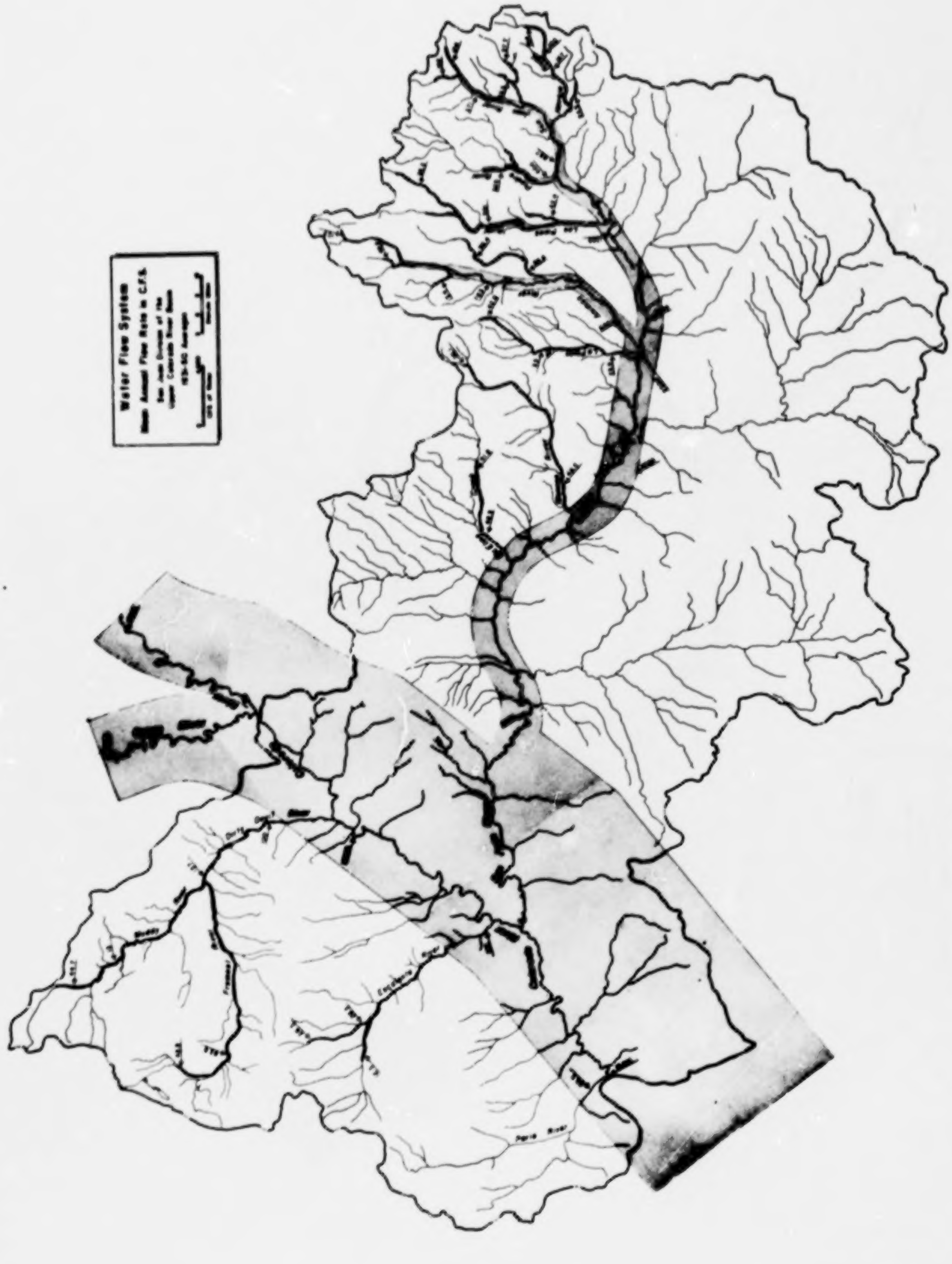


Figure 6.4. Mean annual water flow rates, San Juan division.

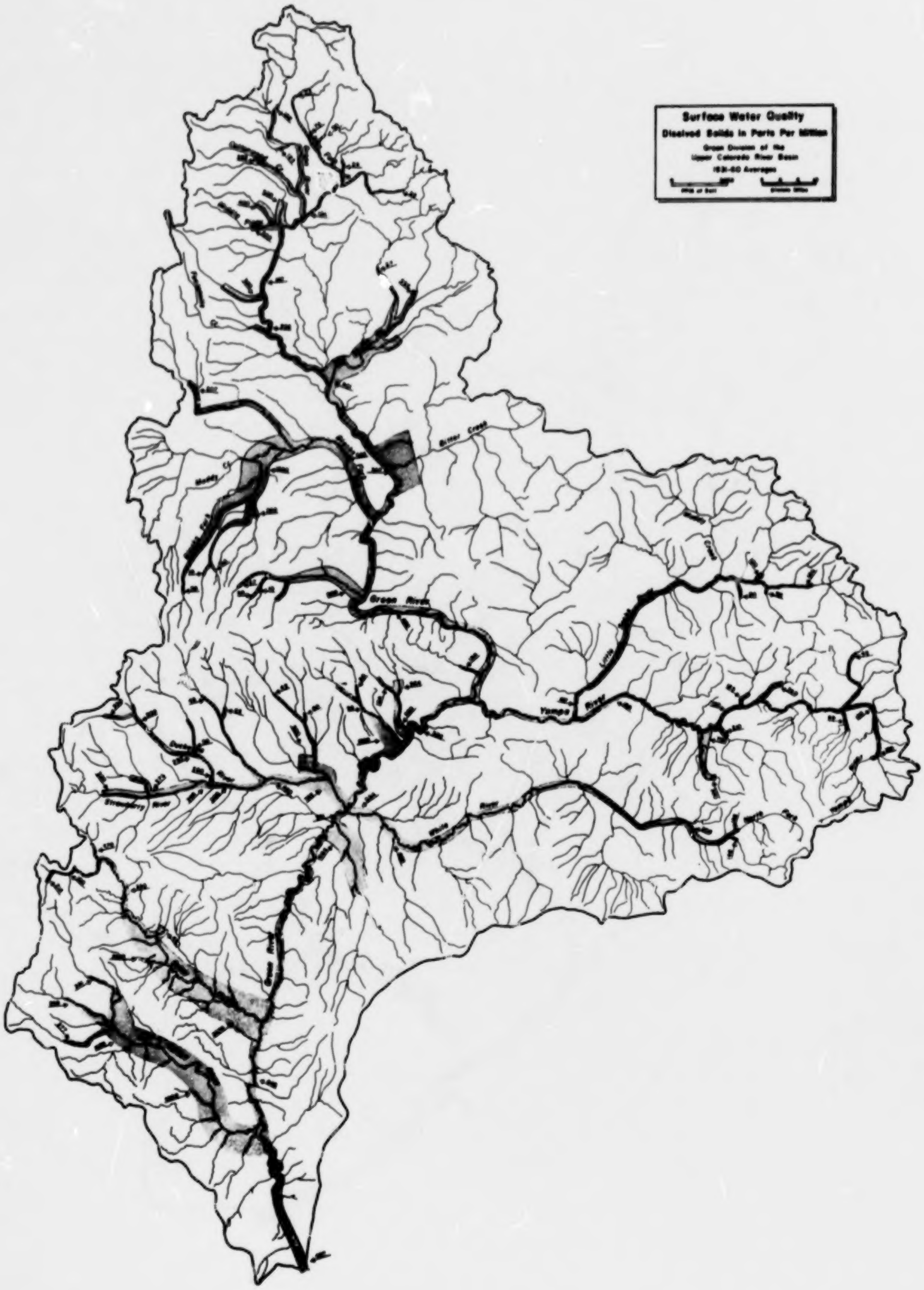

Surface Water Quality
Dissolved Solids in Parts Per Million
Green Division of the
Upper Colorado River Basin
1951-60 Averages
Bitter Creek
Green River
Yampa River
Strawberry River
White River
Muddy Cr.

Figure 6.5. Average salt content in surface waters, Green division.

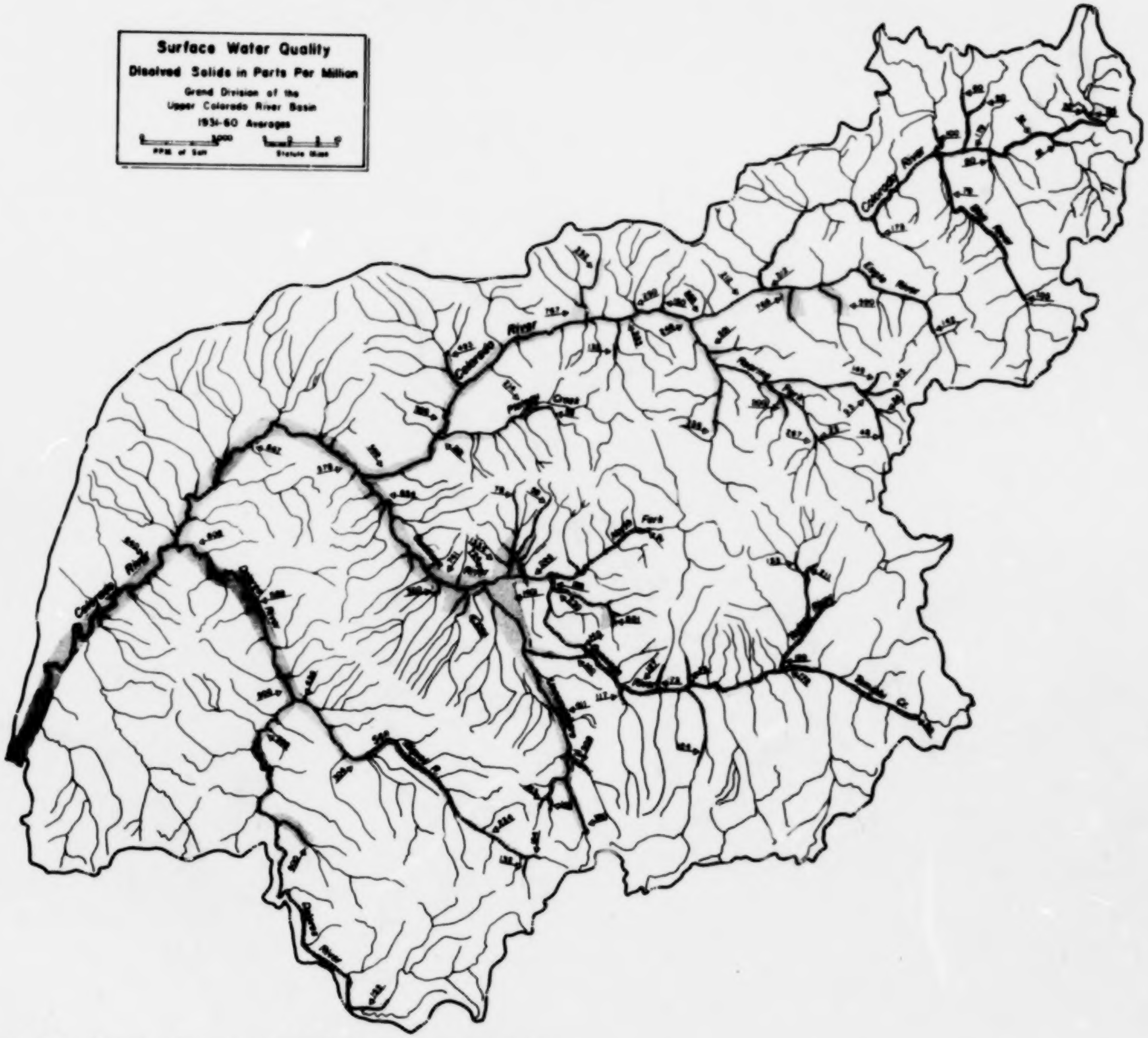

Surface Water Quality
Dissolved Solids in Parts Per Million
Grand Division of the
Upper Colorado River Basin
1931-60 Averages
PPM of Salt
Statute Miles
Colorado River
Eagle River
Dolores River

Figure 6.6. Average salt content in surface waters, Grand division.

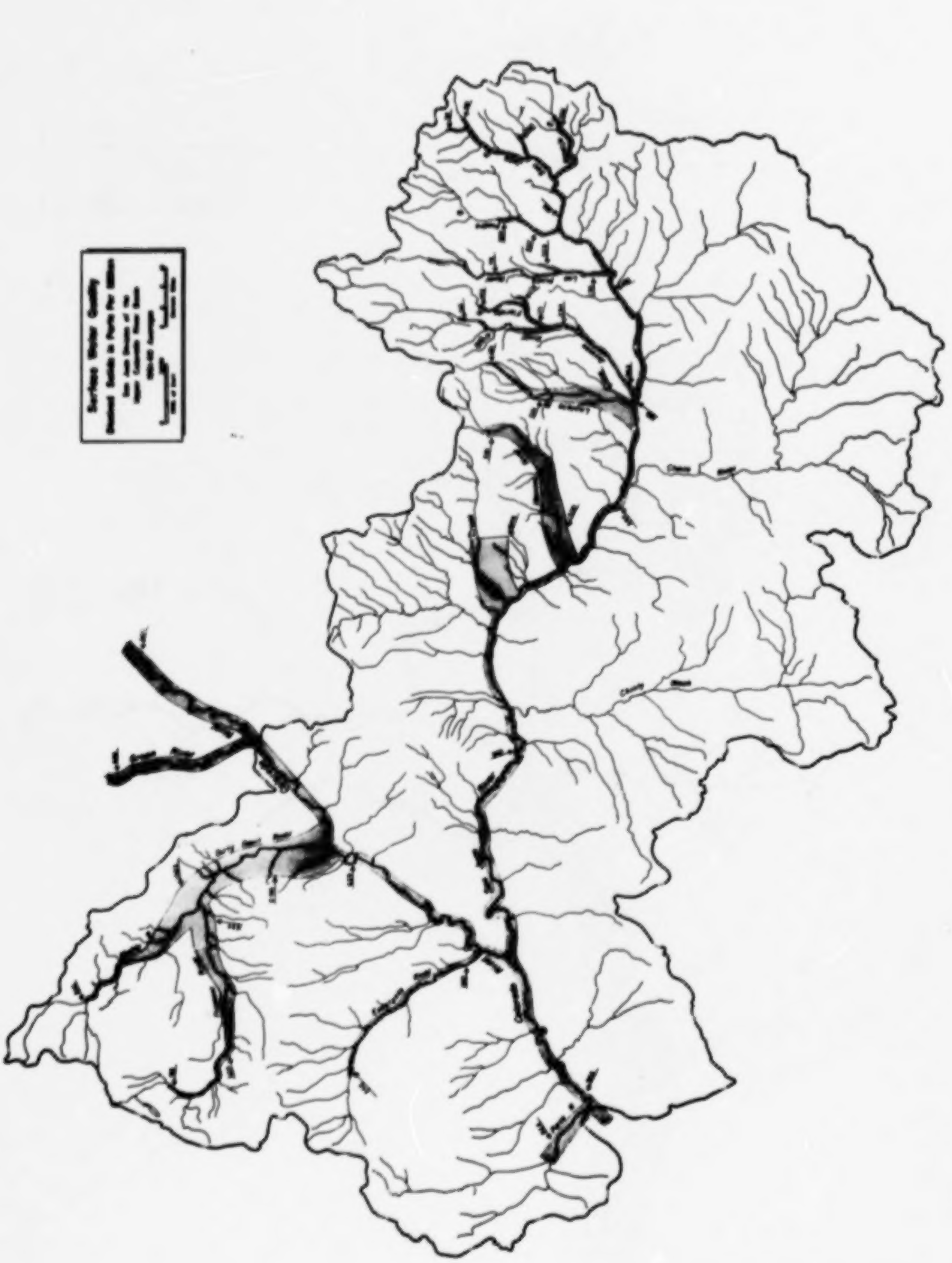


Figure 6.7. Average salt content in surface waters, San Juan division.

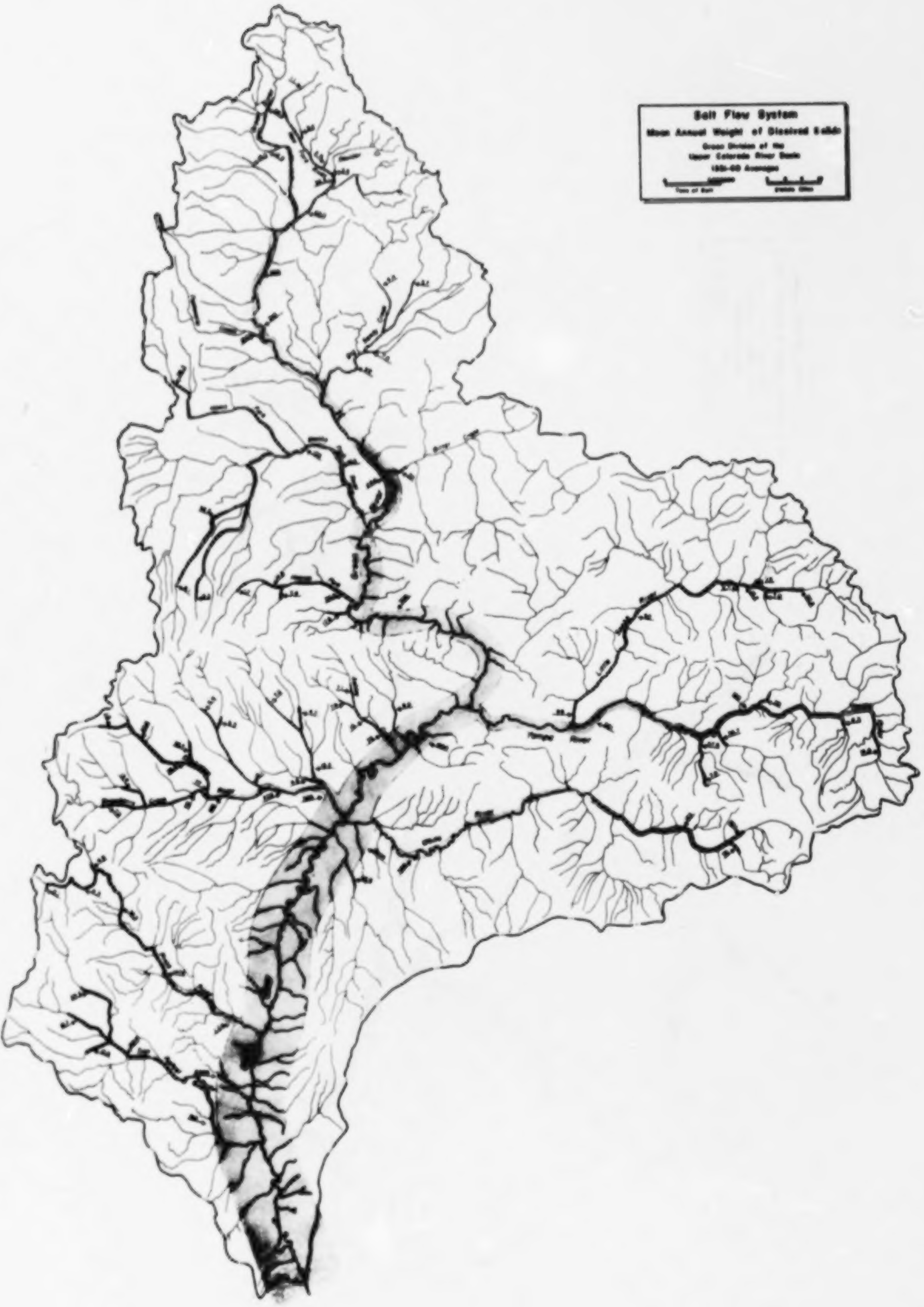

Salt Flow System
Mean Annual Weight of Dissolved Solids
Green Division of the
Upper Colorado River Basin
[illegible] Averages
Tons of Salt
Statute Miles

Figure 6.8. Mean annual salt flow rates, Green division.

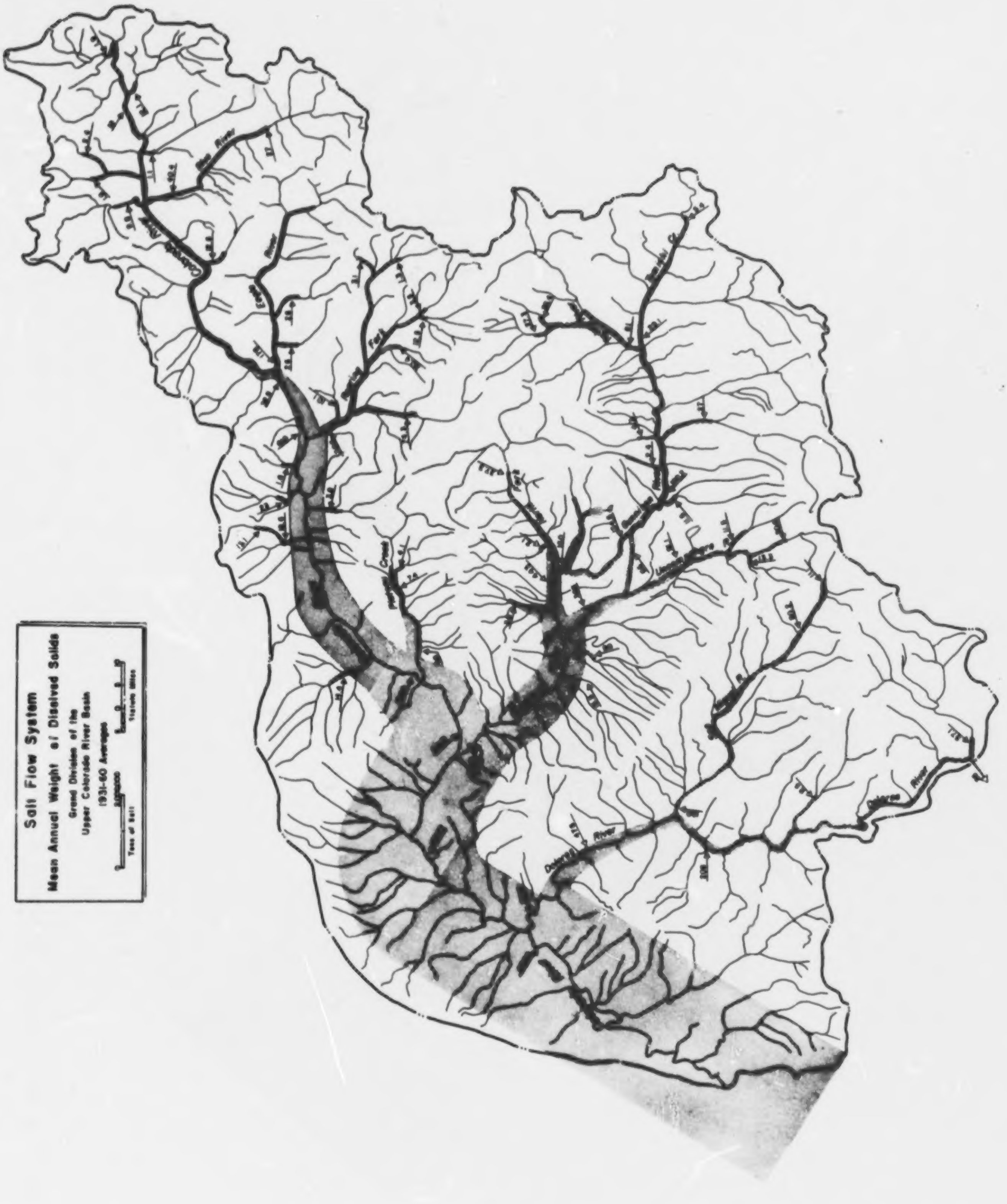

Salt Flow System
Mean Annual Weight of Dissolved Solids
Grand Division of the
Upper Colorado River Basin
1931-60 Averages
Tons of Salt
Statute Miles
Colorado River
Blue River
Eagle River
Roaring Fork
Plateau Creek
Gunnison River
Uncompahgre River
Dolores River

Figure 6.9. Mean annual salt flow rates, Grand division.

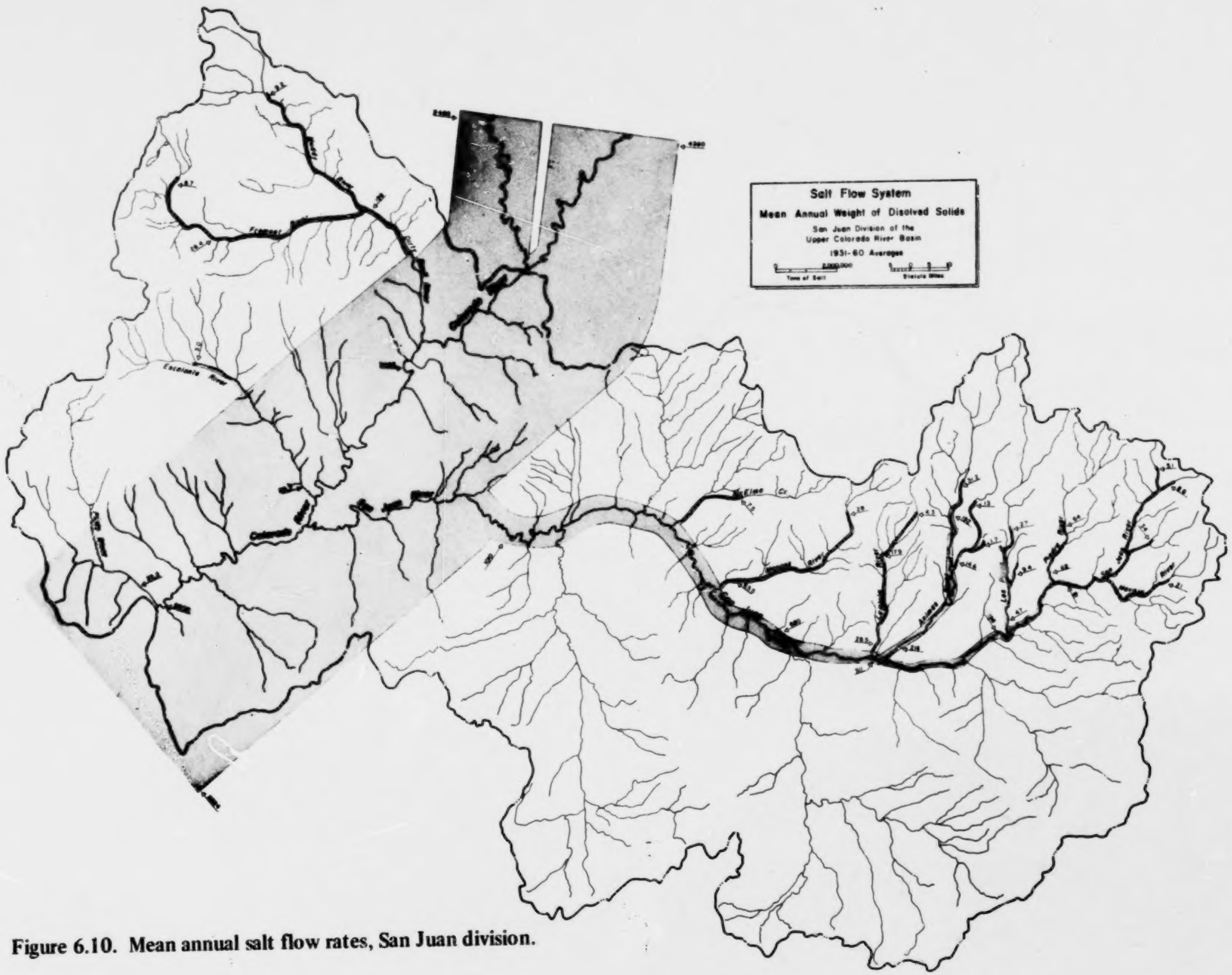

Salt Flow System
Mean Annual Weight of Disolved Solids
San Juan Division of the
Upper Colorado River Basin
1931-60 Averages
Tons of Salt
Statute Miles
Escalante River
Colorado River
San Juan River
Fremont River
McElmo Cr.
Animas
Los Pinos

Figure 6.10. Mean annual salt flow rates, San Juan division.

rates are estimated to be 2,065 cubic feet per second (cfs) and 1,960 cfs, respectively. Yet the Yampa River system contributes only about 400,000 tons of salt per year, compared to approximately 800,000 tons from the Green River at this same point. In the Grand division, at the junction of the Colorado River and the Gunnison River, the Colorado carries about 1,950,000 tons of salt per year, while the Gunnison contributes approximately 1,370,000 tons per year.

Many mineralized thermal springs discharge into streams throughout the basin and contribute to pollution problems from both a salinity and a thermal aspect. Some springs, such as those which discharge into the northward-flowing tributaries of the Duchesne River, also introduce high concentrations of a toxic ion. Iorns et al. (1965) indicate that 183,000 tons of salt annually are added to the Colorado River main stem between the Eagle River and the Shoshone power plant about 17 miles downstream. This reference further indicates that about 59,000 acre-feet of water and 540,000 tons of salt flow annually from mineralized thermal springs within the Upper Colorado River basin.

Suitability for use

A fairly comprehensive treatise of the suitability of the Upper Colorado River basin waters for various uses by man is provided by Iorns et al. (1965), and only a few observations are noted here.

To prevent salinization of the soils and a prohibitively high water table adequate drainage (natural or artificial) is essential to permanent irrigation agriculture. This requirement is of particular concern in areas where irrigation waters carry high salinity concentrations. Under conditions of good drainage the waters of the Upper Colorado River are entirely suitable for irrigation.

The Upper basin waters are generally suitable for domestic uses. In cases where salinity levels exceed 500 ppm some form of treatment, such as mixing with better quality water, is sometimes needed. Because of the low population density, only a small quantity of water is now used for domestic purposes in the basin. Some water is exported from the basin for domestic use elsewhere.

Industrial use of water within the basin has been minimal to date, and quality has not been a restrictive factor.

Subbasin Development

Spatial resolution within the model of the hydrologic and salt flow systems of the Upper Colorado River basin was achieved by dividing the entire basin into 40 subunits, and by considering each subbasin as a modeling unit (Figure 6.1 and Table 6.1). The budget or mass balance concept was applied to link the various submodels into a single model of the entire basin. With this approach the outflow of water and salt from one subbasin constituted input functions to the adjacent downstream subbasin.

The criteria used in establishing subbasin boundaries were the availability of data and the degree of resolution that seemed required for the model. Sufficient data were required to verify (calibrate and test) the model of each subbasin. The area associated with each subbasin is illustrated with a map that indicates in a general manner the location of the irrigated lands, meteorological stations, stream gaging stations, and water quality monitoring stations (Appendix A).

Data Evaluation

As discussed in Chapter V, for a particular level of system definition in terms of time and space resolution, the accuracy with which a computer model is able to represent the prototype depends to a large extent upon the quantity and quality of field data. In this study a time increment of one month was adopted and the Upper Colorado Riber basin was divided into 40 subbasins. A vast amount of basic data was, therefore, necessary before modeling could begin.

The model boundaries

For each subbasin the area included in the model was limited to the valley floor which is the area most affected by the activities of man. Other studies have demonstrated the applicability of the simulation approach to an entire watershed, including the agriculture area (Riley et al., 1966 and 1967). The surrounding mountainous area was not neglected, however, because both the surface and subsurface contributions from this source to the valley floor were included as inputs to the model.

The total area of each subbasin and the irrigated acreage within each are tabulated in Appendix B (Tables B-1, B-2, and B-3) for the Green, Grand, and San Juan divisions, respectively. These tables were prepared from unpublished data of the Bureau of Reclamation (USBR) and the Soil Conservation Service (SCS), and from published data of the U.S. Agricultural Census and the Geological Survey (Iorns et al., 1964 and 1965). No thorough investigation of the irrigated lands has been conducted in recent years, and acreage figures from various sources contain some discrepancies.

The physical or geographic location of the irrigated lands (Appendix A) is important because it dictates the model boundaries. Insofar as possible these boundaries were related so that input monitoring points for water and salt were situated upstream from the agriculture lands within the subbasin.

Meteorological data

Evapotranspiration uses by agricultural crops and phreatophytes were estimated from climatological data (U.S. Weather Bureau, 1950-66). For subbasins which contained more than one climatological station, a weighting factor was assigned to each station to indicate the fraction or percentage of the total precipitation or temperature value contributed by that particular station (Appendix C). The weighting factor for a station was based on an estimate of the portion of the total agricultural land contained within the subbasin considered to be represented by conditions measured at the particular station. The relevant monthly precipitation and temperature data, as well as the mean monthly and mean annual values of both temperature and precipitation are also recorded in Appendix C.

Table 6.1. Subbasins with their associated hydrologic areas and years utilized in model development.

Subbasin	Hydrologic Drainage Area, Sq. Miles	Model Years
Green Division		
New Fork River Basin	1230	1965-66
Green River above LaBarge, Wyoming	2320	1965-66
Green River above Fontenelle Reservoir	950	1965-66
Big Sandy Creek Basin	1610	1962-63
Green River above Green River, Wyoming	1391	1964-65
Blacks Fork River Basin	3100	1964-65
Green River above Flaming Gorge Dam	4500	1965-66
Little Snake River Basin	3600	1965-66
Yampa River Basin	3600	1965-66
Green River above Jensen, Utah	3100	1964-65
Ashley Creek Basin	386	1964-65
Duchesne River above Duchesne, Utah	1700	1965-66
Duchesne River above Randlett, Utah	2220	1964-65
White River Basin	4020	1964-65
Green River above Ouray, Utah	1774	1964-65
Price River Basin	1500	1964-65
Green River above Green River, Utah	3600	1964-65
San Rafael River Basin	1670	1964-65
Grand Division		
Colorado River above Hot Sulphur Springs, Colo.	840	1965-66
Eagle River Basin	957	1965-66
Colorado River above Glenwood Springs, Colo.	2764	1965-66
Roaring Fork River Basin	1451	1964-65
Colorado River above Plateau Creek	2064	1959-60
Plateau Creek Basin	604	1963-64
Gunnison River above Gunnison, Colorado	2030	1964-65
Gunnison River above North Fork Gunnison River	2258	1964-65
Uncompahgre River Basin	1110	1960-61
Gunnison River above Grand Junction, Colorado	2530	1965-66
Colorado River above Colorado-Utah State Line	1557	1964-65
San Miguel River Basin	1550	1964-65
Dolores River Basin	3030	1964-65
Colorado River above Cisco, Utah	1356	1964-65
San Juan Division		
San Juan River above Arboles, Colorado	1230	1964-65
San Juan River above Archuleta, New Mexico	2030	1964-65
Animas River Basin	1360	1962-63
San Juan River above Farmington, New Mexico	2620	1964-65
LaPlata River Basin	583	1961-62
San Juan River above Shiprock, New Mexico	5077	1964-65
San Juan River above Bluff, Utah	10100	1964-65
Colorado River above Lee's Ferry, Arizona	19940	1964-65

Missing temperature data were estimated by lapsing the monthly records from another station in the subbasin. Missing precipitation data were estimated from recorded data at adjacent stations (Appendix A). Evaporation data, though not listed in Appendix C because of the limited amount available, were used where possible as a measure of the depletion from large water surface areas.

The essential inputs to the model are river inflow, tributary inflow, imports, and groundwater inflow (Figure 3.1). The locations at which the hydrologic inputs and outputs for each subbasin were measured are illustrated in Appendix A.

Streamflow data were obtained from the surface water runoff records published by the Geological Survey (1964, 1961-67). A digital computer program was developed which extends streamflow records at a particular station through correlation procedures with an appropriate station of longer record. A listing of the computer program and sample output are presented in Appendix D. The mathematical model used by the correlation program is an equation of the form

$$y = A x^{B} \quad \ldots\ldots. \quad (6.1)$$

in which y is the predicted monthly streamflow, x is the observed monthly streamflow at the base station, A is the intercept on the y-axis of a log-log plot of the data, and B is the slope of the line which best fits the data plotted on log-log paper. The values of A and B are determined from observed values of x and y. The correlation coefficient, R^2, indicates the degree to which the model is able to explain variations in y (the correlated station) as a function of variations in x (the base station).

For stations requiring an extension of water flow records, correlation relationships were developed for each month on the basis of the model of Equation 6.1. In the event that the correlation coefficient was somewhat low for a specific month (or months), an alternate base station was sought and new relationships were developed as needed. Generally, only one or two base stations were required to obtain good correlations for every month of the year. Using this approach, the volume of ungaged inflow was minimized for each subbasin.

The stations utilized in determining the measured and estimated stream inflows to each subbasin within the Upper Colorado River basin together with corresponding periods of record are tabulated in Appendix D. The table also distinguishes between observed and correlated periods of record. For most subbasins diversions, depletions, and return flows associated with municipal and industrial uses were negligible.

The digital computer program presented in Appendix D also was used to estimate mean annual water discharge rates for the 1931-60 time period as depicted in Figures 6.2, 6.3, and 6.4. These figures, as illustrated, depict the flows as though the physical conditions in existence during 1960 in terms of reservoir storage and water diversions prevailed throughout the entire 1931-1960 period.

Canal diversions

Because of the significant effect of irrigation upon the hydrologic and salinity flow systems within the Upper Colorado River basin, the time distribution and the quantities of water conveyed to irrigated land areas through ditches and canals was defined as accurately as possible. Most of the canal diversion records available in the Upper basin were recorded in the states of Utah and Colorado. In general, irrigation diversions have not been measured in the states of Wyoming and New Mexico. For all states the office of the state engineer was very helpful in providing information and insight regarding the probable volume and distribution of irrigation diversions.

The irrigation diversion records from Colorado required a somewhat different analysis than those from the other states. The irrigated area of the state is divided into a number of water districts, each of which is supervised by a watermaster who maintains a field book record of most important irrigation diversions within his district. Thirty-four such irrigation districts fall within the Upper Colorado River basin, and these districts are contained in four of the seven irrigation divisions of the state. The state engineer and the four irrigation division engineers considered that sufficient accuracy could be achieved by distributing the yearly diversions of an irrigation district on the basis of records from selected ditches within that district. Ditches and canals most representative of the water distribution patterns of a particular district were selected by consulting with the watermaster and division engineer responsible for that district. The number of canals and ditches selected varied from district to district, but in all cases the distribution pattern adopted for a district was the average pattern for all ditches selected. Discontinued records were extended where necessary by using a linear correlation model. A linear model, rather than the log-log model of Equation 6.1, was adopted because of some zero-valued data.

In Wyoming, irrigation diversions were not measured until 1967, when a partial monitoring program was initiated. These records were extrapolated to provide estimates of diversions for the years used in the model verification. Similar circumstances existed in New Mexico where only miscellaneous records were available.

For some subbasins independent estimates of irrigation diversions were not possible. In these instances diverted quantities were carried as unknowns and estimated through the model verification procedure.

The recorded or estimated canal diversions utilized in the study are tabulated in Appendix E. For each subbasin the table lists monthly diversions in acre-feet units for a two-year period. Also tabulated is the annual volume of water diverted per acre of irrigated land.

The nature and purpose of the reservoirs in the Upper basin were ascertained (Appendix E). Data for some of the reservoirs were extracted from Iorns et al. (1965). Large reservoirs, such as Flaming Gorge, which are used mainly for power generation, were included in the hydrologic model only from the standpoint of their effects upon the time distribution of the water flow through the system. Recorded outflows from irrigation reservoirs during the summer were generally considered as a water supply to the irrigated lands. Reservoirs having a capacity of less than 1,000 acre-feet were neglected. Reservoirs in the 1,000 to 5,000 acre-feet capacity range and for which records were unavailable were also neglected. Adequate records were obtained for all reservoirs having capacities in excess of 5,000 acre-feet.

The remaining source of irrigation water in the Upper Colorado River basin is groundwater storage. However, use from this source is so small as to be negligible. Only in one instance was pumped water considered in the model, and in this case withdrawal data were obtained.

Vegetative distribution

The greatest single withdrawal of water from the hydrologic system of the Upper Colorado River basin is by evapotranspiration. A correct assessment of the volume of water lost in this way requires a reasonably good approximation of the spatial distribution and transpiration rates of various plant species. The total irrigated areas are fairly well defined, but the census of crops and other vegetative cover on this land is not nearly so complete. The problem is further complicated by crop rotation and fallowing practices which introduce a time dependency.

The only recent land-use surveys that could be found pertained to the State of Utah. Though not yet published, these data were obtained for the Duchesne River and Ashley Creek Basins from the Division of Water Resources of Utah (1968) in Salt Lake City, Utah. For the remainder of the irrigated lands within the Upper basin, the crop distribution data were taken from the U.S. Agricultural Census of 1964. In some areas supplemental information was obtained from the U.S. Bureau of Reclamation. The crop distribution patterns used in the model for each subbasin are tabulated in Appendix F.

Except for a few areas, information is meager on the distribution of phreatophytes within the Upper Colorado River basin. The U.S. Geological Survey is preparing a report (Robinson, 1968) which will include estimates of phreatophyte distribution by river systems within the Upper basin. From an advance copy of this information and additional data obtained from the USDA, Soil Conservation Service (1962, 1965, and 1966), land acreages covered by various species of phreatophytes were estimated for each subbasin (Appendix F). These data enabled evapotranspiration losses by phreatophytes to be included in the model.

A modification suggested by Phelan and others (1962) to the formula proposed by Blaney-Criddle (1950) for the estimation of potential evapotranspiration was discussed in Chapter III. This modification in part computes consumptive use as a function of the physiology and stage of growth of the crop through a time-varying coefficient, designated in Equation 3.25 as k_c. The k_c values for the various crop varieties and phreatophytes considered in the study are tabulated in Appendix F (Table F-4). These tabulated values were taken from curves prepared by the Soil Conservation Service (1964).

Soil moisture capacity

Moisture supplies available to plants and stored within the root zone were included in the model (Equations 3.28 and 3.29). Estimates of the available soil moisture storage capacity for broad soil types within the irrigated area of each subbasin were made by using Table 3.1 in conjunction with data from various field investigations. Sources of these data included soil surveys by the U.S. Department of Agriculture (1955, 1959, 1962, and 1967), state soils maps, Thaine et al. (1967), Wilson, Hutchings, and Shafer (1968), and field investigations conducted by the Bureau of Reclamation.

Average values for the available soil moisture storage capacity within the irrigated land of each subbasin are tabulated on the potentiometer setting summary sheet included in Appendix H.

Water quality data

Water quality data were obtained from various federal and state agencies, including the Federal Water Pollution Control Administration, the Bureau of Reclamation, the Geological Survey, and the Utah State Division of Health. In addition, data from miscellaneous samples were available from sources such as oil companies. Groundwater salinity information was particularly sparse, and it was, therefore, necessary to make the simplifying assumptions discussed in Chapter IV.

All available water quality data were based on measurements taken at a point in time, whereas monthly average values were required for input to the model. A digital computer program was written to calculate monthly average values for both water flow rates and concentrations of total dissolved solids (TDS) from any random number of point measurements made during a month (Appendix G). Diurnal fluctuations are neglected in this program. Estimations of the monthly average TDS levels are weighted on both a time and a water discharge basis.

In the record phase of the computer program of Appendix G, the estimated average monthly and yearly TDS values are used to formulate a mathematical model relating TDS as the dependent variable with time (or month) and average monthly water flow rate. Using a multiple regression analysis, a third order expression for water flow rate and a second order expression for time, plus interrelationships between these two independent variables, were combined to form a mathematical model or equation which expressed TDS as a function of eight terms. A stepwise elimination process then consecutively excludes from the equation those terms of least statistical significance. For example, for Blacks Fork River near Millburne, the third variable is the first to be eliminated from the equation because it contributes the least to the statistical correlation (Appendix G). The stepwise elimination process is continued until all variables have been removed. At each step the new mathematical relationship is examined statistically, and the relative contribution of the preceding deleted term is computed. For example, Appendix G illustrates two mathematical relationships which were developed for the Blacks Fork River near Millburne. In the first relationship, TDS is expressed as a function of both flow and time (month) utilizing all eight terms. The correlation coefficient, R^2, is 0.817. In the second relationship, TDS is a function of a third order expression in terms of water flow rate only, and the correlation is 0.580.

Mathematical relationships developed as described in the preceding paragraph were used to estimate the average TDS level for any month on a stream for which the corresponding water flow rate was known. The relationships also were applied to estimate monthly salinity concentrations of streams with no salinity records but with a point of measured water discharge and similar geologic characteristics to those watersheds for which the relationships were developed. For example, water discharge rates are gaged from both east and west forks of Smiths Fork. Salinity records on these two tributaries are few, but their watersheds are related in geologic origin to that of Blacks Fork River. It was, therefore, considered reasonable to use the mathematical relationships developed for the Blacks Fork River (Appendix G) for estimating TDS concentrations on the east and west forks of Smiths Fork.

In addition to its use in developing the monthly relationships described above, the computer program of Appendix G was applied to the formulation of regression equations between mean yearly values of TDS and water flow rate as illustrated by relationships proposed for the Blacks Fork River near Marston. For many stations the period of record for water discharge rate is much longer than that for salinity measurements. Relationships between TDS and water flow rate for stations of this nature were used to extend the salinity records by predicting average annual TDS values for the period of water flow measurements. In this way and by adjusting the water flow records at key stations to 1960 conditions, average 1931-60 salinity flow diagrams were prepared for the Upper Colorado River basin (Figures 6.5, 6.6, and 6.7). Water flow stations at which quality information (either measured or estimated) is also available are tabulated in Appendix D.

Simulation of the White River Subbasin - An Illustrative Example

The basic model developed for the hydrologic system as outlined in Chapter III and the hydro-salinity model formulated in Chapter IV are both general in nature, and as such are applicable to any hydrologic system. As discussed in Chapter V, the models were synthesized on a computer and then characterized for each particular subbasin through a verification procedure wherein specific coefficients or parameters (Chapters III and IV) are determined. The verification procedure that was followed in developing a hydro-salinity model of the Upper Colorado River basin will be illustrated by referring to a specific example, namely the White River subbasin of the Green division. Although system processes differ somewhat from subbasin to subbasin, it was possible to follow the same basic procedure in verifying models for each of the selected subbasins within the Upper basin.

The steps followed and alternatives considered in the development of the hydro-salinity model for the White River subbasin are described in some detail in the following paragraphs. References are made to appendices which describe the flow system of other subbasins in the river systems. The problems associated with scaling, model definition, and model verification, as they occurred for the White River, illustrate the techniques used in solving similar problems in the other subbasins. Thus, the White River subbasin illustrates many aspects of the approach used in modeling the remaining subbasins of the Upper Colorado River basin. The special peculiarities of each subbasin are considered in Chapter VII.

General description of the White River subbasin

The White River subbasin lies primarily in west-central Colorado, with the Colorado River on the south and the Yampa River on the north. The lowest portion of the drainage area lies in east-central Utah at the point of confluence of the White and Green Rivers. However, for this study, the White River subbasin is assumed to terminate at the Geological Survey water quality monitoring site located near Watson, Utah. This designation assigns the White River subbasin an area of approximately 4000 square miles.

Early settlement and development in the subbasin occurred on the natural meadows bordering the river. The first settlement of any magnitude occurred in the town of Meeker, Colorado, around 1881. Livestock production formed the early economic base for the subbasin, with an agricultural enterprise devoted essentially to the raising of feed and forage crops. About 1940, the economic base was expanded by the development of oil and gas resources near Rangley, Colorado. This area is now the largest producer of oil and natural gas in the State of Colorado. The estimated population of the subbasin in 1960 was about 5500 persons, with more than half of these living in the towns of Meeker and Rangley.

The elevation of the subbasin varies from approximately 5000 feet at the outlet to about 12,000 feet in the upper reaches of the headwaters. Because of this elevation difference, the climate is variable with wide temperature extremes in the settled areas. The average annual frost-free period for cropland varies from about 50 to 125 days. Similarily, the average annual precipitation varies from 9 to 30 inches.

At its higher elevations, the subbasin is underlain by essentially tertiary volcanics and rocks of the Paleozoic age. These formations are relatively resistant to solution by moving water so the water quality monitored at Buford, Colorado, is generally low in total dissolved solids. The lower elevation and downstream portions of the subbasin are underlain by predominantly Mancos shale, Green River, and Wasatch formations. The Green River formation is somewhat resistant to solution by water and is generally found in association with oil-shale beds. The Mancos shale and Wasatch formations are comparatively soluble and contribute significantly to the total dissolved solids load transported by the water. The total dissolved solids concentrations are high, averaging approximately 450 ppm, at the outflow point from the subbasin near Watson, Utah.

Model development

The first step in developing a hydro-salinity model of the White River subbasin, was defining the model boundaries. The boundaries were established so as to include all agricultural lands in the valley bottoms of the White River and its tributary streams (Appendix A). Approximately 29,200 acres of irrigated land are contained within this subbasin (Table B-1, Appendix B). The points at which the hydrologic and salinity inflows to the model area were either measured or estimated are illustrated in Appendix A. Surface inflows from the surrounding watershed occur at these points. Since the gaging of water flows on Big Beaver Creek was discontinued in September of 1964, the digital computer program discussed in the previous section of this chapter and illustrated in Appendix D was used to extend the record of this stream past the discontinued date.

Salinity data were available and relatively complete at both input and output points for the years 1964 and 1965, and these data were used in verifying the White River subbasin model. Water salinity data were lacking for both Big Beaver and Coal Creeks. However, because of the topographic and geologic similarity of these drainage areas to that of South Fork of the White River, salinity concentration measurements for the South Fork near Buford were also applied to the Big Beaver and Coal Creeks. Salinity data for the White River near Buford and the South Fork of the White River at Buford were converted to mean monthly values on a flow and time basis utilizing the digital computer program illustrated in Appendix G. Historical salinity data were unavailable for the South Fork of the White River at Buford for the period January through August of 1964. The missing records for this period were therefore estimated by using the second phase of the computer program of Appendix G.

The total measured inflow by month of water and salts to the White River Basin for the years 1964 and 1965 are tabulated in Tables 6.2 and 6.3, both in acre-feet and in volts. The voltages represent inputs, scaled on both a time and a magnitude basis, to the analog computer on the step potentiometers described in Chapter V. The agricultural area of the basin of 29,200 acres was applied in converting monthly water flow volumes in acre-feet to depths in inches. One inch depth of water over this area is equivalent to 2440 acre-feet of water. The monthly salt load transported by the water was recorded as the weight in tons dissolved in the monthly water flow volume. These monthly values for both water and salt were input to the computer program as indicated by Figure 5.2.

Ungaged inflows of both water and salt to the White River basin were computed by Equations 3.3, 3.4, 4.5, and 4.6. Equation 3.4 was applied by correlation with the White River near Buford, Colorado. The coefficients used in these equations were established by the verification procedure and are reported in Table 6.4. Because salinity records, either measured or estimated, were available at all water flow rate gaging stations in the subbasin the term $S^{is}_{r\Delta Q}(u)$ was equal to zero. In addition, it was assumed that the average salinity content of water entering the system from unmeasured sources, $\bar{C}_{is}$ (u), equaled that of measured water inflows, $\bar{C}_{is}$ (m). Expressed in the form of an equation for the White River basin:

$$\bar{C}_{is}(u) = \bar{C}_{is}(m) \quad . \; . \; . \; . \; . \quad (6.2)$$

Two reasons are given for justifying this assumption: (1) the ungaged inflows of both water and salt were small in comparison to the corresponding measured inputs, and

Table 6.2. Hydrologic and salinity inputs to the White River Subbasin for 1964.[a]

	Surface inflow, A.F.									Scaled growth stage coefficient						
Month	White R. nr. Buford	So. Fork White R. at Buford	Big Beaver Creek	Coal Creek	Input from stream correlations	Input salinity concentration tons/inch	Precipitation inches	Temperature F	Percent daylight hours x 5	crop k_c 1	crop k_c 2	phreatophyte k_c	Canal diversions A.F.	Percentage interchange based on outflow	Water outflow at Watson, Utah A.F.	Salt outflow at Watson, Utah tons
JAN	6600 (2.7)	4790 (2.0)	111 (-)	86 (-)	(6.6)	667 (66.7)	0.66 (13.2)	18.1 (18.1)	(33.7)	(38)	(22)	(1.4)	—	43.0	17100 (7.0)	15800 (15.8)
FEB	6980 (2.9)	5170 (2.1)	138 (0.1)	92 (-)	(7.0)	652 (65.2)	0.56 (11.2)	19.3 (19.3)	(33.7)	(45)	(26)	(1.7)	—	38.5	18760 (7.7)	16050 (16.0)
MAR	7650 (3.1)	6260 (2.6)	202 (0.1)	139 (0.1)	(7.7)	629 (62.9)	1.34 (26.8)	26.3 (26.3)	(41.5)	(49)	(32)	(1.8)	—	33.0	26040 (10.4)	21570 (21.6)
APR	8540 (3.5)	6810 (2.8)	704 (0.3)	311 (0.1)	(8.5)	599 (59.9)	2.72 (54.4)	40.9 (40.9)	(44.6)	(56)	(37)	(2.5)	12000 (5.0)	29.5	30320 (12.4)	26760 (26.8)
MAY	38530 (15.8)	39790 (16.3)	5250 (2.2)	1050 (0.4)	(38.5)	396 (39.6)	1.63 (32.6)	51.9 (51.9)	(50.0)	(60)	(40)	(3.0)	32000 (13.1)	15.7	84210 (34.5)	34820 (34.8)
JUNE	49900 (20.5)	62620 (26.6)	1440 (0.6)	770 (0.3)	(49.9)	350 (35.0)	2.07 (41.4)	58.5 (58.5)	(50.4)	(63)	(41)	(3.0)	57000 (23.4)	13.7	99350 (40.9)	33370 (33.4)
JULY	20490 (8.4)	15070 (6.2)	50 (-)	108 (-)	(20.5)	556 (55.6)	0.79 (15.8)	68.8 (68.8)	(51.2)	(62)	(41)	(3.0)	23000 (9.4)	29.7	30220 (12.4)	19190 (19.2)
AUG	12980 (5.3)	9560 (3.9)	39 (-)	119 (0.1)	(13.0)	579 (57.9)	2.08 (41.6)	62.7 (62.7)	(47.8)	(60)	(40)	(3.0)	9500 (3.9)	34.0	24680 (10.2)	20140 (20.1)
SEPT	9560 (3.9)	6980 (2.9)	23 (-)	94 (-)	(9.6)	600 (60.0)	0.59 (11.8)	55.5 (55.5)	(42.0)	(56)	(38)	(2.9)	12000 (5.0)	44.0	15700 (6.5)	12900 (12.9)
OCT	9780 (4.0)	6520 (2.7)	46 (-)	86 (-)	(9.8)	600 (60.0)	0.22 (4.4)	47.9 (47.9)	(38.9)	(52)	(35)	(2.7)	7500 (3.0)	38.5	20060 (8.2)	15580 (15.6)
NOV	8960 (3.7)	6240 (2.6)	177 (0.1)	101 (-)	(9.0)	589 (58.9)	1.50 (30.0)	31.0 (31.0)	(33.6)	(45)	(29)	(2.2)	—	37.5	20350 (8.4)	16670 (16.7)
DEC	9310 (3.8)	6370 (2.6)	182 (0.1)	111 (-)	(9.3)	678 (67.8)	2.20 (44.0)	25.3 (25.3)	(32.7)	(38)	(24)	(1.6)	—	37.0	21540 (8.9)	20450 (20.4)

---

[a] Figure in parenthesis are computer-voltages.

Table 6.3. Hydrologic and salinity inputs to the White River Subbasin for 1965.[a]

	Surface inflow, A.F.									Scaled growth stage coefficient						
Month	White R. nr. Buford	So. Fork White R. at Buford	Big Beaver Creek	Coal Creek	Input from stream correlations	Input salinity concentration tons/inch	Precipitation inches	Temperature F°	Percent daylight hours x 5	crop k_c 1	crop k_c 2	phreatophyte k_c	Canal diversions A.F.	Percentage interchange based on outflow	Water outflow at Watson, Utah A.F.	Salt outflow at Watson, Utah tons
JAN	8710 (3.6)	6530 (2.7)	103 (–)	86 (–)	(8.7)	645 (64.5)	1.10 (20.2)	25.4 (25.4)	(33.7)	(38)	(22)	(1.4)	—	35.0	23350 (9.6)	21150 (21.2)
FEB	7600 (3.1)	6650 (2.7)	229 (0.1)	119 (0.1)	(7.6)	615 (61.5)	0.89 (17.8)	24.3 (24.3)	(33.7)	(45)	(26)	(1.7)	—	34.0	22390 (9.2)	19430 (19.4)
MAR	7870 (3.2)	6080 (2.5)	385 (0.2)	206 (0.1)	(7.9)	668 (66.8)	0.77 (15.4)	27.1 (27.1)	(41.5)	(49)	(32)	(1.8)	—	28.0	33460 (13.7)	31030 (31.0)
APR	10750 (4.4)	7760 (3.2)	1261 (0.5)	441 (0.2)	(10.8)	596 (59.6)	1.14 (22.8)	42.9 (42.9)	(44.6)	(56)	(37)	(2.5)	16000 (6.5)	26.5	35100 (14.4)	33220 (33.2)
MAY	45000 (18.5)	33160 (13.6)	6511 (2.7)	1890 (0.8)	(45.0)	409 (40.9)	2.94 (58.8)	50.4 (50.4)	(50.0)	(60)	(40)	(3.0)	57000 (23.4)	14.0	98050 (40.3)	45840 (45.8)
JUNE	71340 (29.3)	80610 (33.1)	2707 (1.1)	1190 (0.5)	(71.3)	430 (43.0)	1.98 (39.6)	57.3 (57.3)	(50.4)	(63)	(41)	(3.0)	62000 (25.4)	10.5	157700 (64.8)	59840 (59.8)
JULY	34290 (14.1)	23810 (9.8)	254 (0.1)	285 (0.1)	(34.3)	436 (43.6)	2.74 (44.8)	65.3 (65.3)	(51.2)	(62)	(41)	(3.0)	30000 (12.3)	17.5	69380 (28.5)	45580 (45.6)
AUG	18250 (7.5)	11790 (4.8)	244 (0.1)	165 (0.1)	(18.3)	599 (59.9)	0.90 (18.0)	62.2 (62.2)	(47.8)	(60)	(40)	(3.0)	25000 (10.2)	29.0	31910 (13.1)	23520 (23.5
SEPT	14340 (5.9)	9810 (4.0)	306 (0.1)	131 (0.1)	(14.3)	645 (64.5)	2.00 (40.0)	50.5 (50.5)	(42.0)	(56)	(38)	(2.9)	13000 (5.3)	28.0	32520 (13.4)	23220 (23.2)
OCT	10710 (4.4)	6520 (2.7)	159 (0.1)	119 (0.1)	(10.7)	563 (56.3)	0.30 (6.0)	48.7 (48.7)	(38.9)	(52)	(35)	(2.7)	—	28.0	33560 (13.8)	22780 (2.8)
NOV	9810 (4.1)	6240 (2.6)	280 (0.1)	148 (0.1)	(9.8)	579 (57.9)	1.32 (26.4)	38.1 (38.1)	(33.6)	(45)	(29)	(2.2)	—	31.0	27800 (11.4)	19890 (19.9)
DEC	8410 (3.5)	6370 (2.6)	158 (0.1)	98 (–)	(8.4)	632 (63.2)	2.99 (59.8)	25.5 (25.5)	(32.7)	(38)	(24)	(1.6)	—	32.5	26580 (10.9)	21940 (21.9)

[a] Figure in parenthesis are computer-voltages.

(2) geologic conditions at the areas of origin are generally similar for both the gaged and ungaged inflows.

Recorded precipitation and temperature values for the years 1964 and 1965 were weighted according to the procedure discussed in the preceding section. The weighting factors are tabulated in Table C-1 (Appendix C), and the weighted values of temperature and precipitation are presented by Tables 6.2 and 6.3. These values were input to the computer model as indicated by Figure 5.2 and discussed in Chapter V. For purposes of magnitude scaling, precipitation quantities were input to the computer at 20 times the recorded values.

The evapotranspiration relationship used in the model required, in addition to mean monthly temperature, the monthly percentage of annual daylight hours and a monthly crop growth stage coefficient, k_c. Values for the percent daylight hours (Tables 6.2 and 6.3) were incorporated into the computer program at 5 times their actual value. The two k_c columns listed in Tables 6.2 and 6.3 for agricultural crops represent a consolidation on an area weighted basis of k_c values for the four major crops within the subbasin. This consolidation was necessary in order to reduce the amount of computer hardware required to input the k_c values to the program. The cropping pattern was considered to be 27 percent alfalfa, 34 percent pasture, 10 percent grain, and 29 percent clover (Appendix F). As is indicated by Tables 6.2 and 6.3, it was necessary to apply a different magnitude scaling factor to the k_c values for phreatophytes than to those for agricultural crops. The area of phreatophytes within the subbasins was considered to be equivalent to a concentrated or heavy stand of 3800 acres. Factors for the percent daylight hours and vegetative growth stage coefficients were input to the computer program at points indicated by Figures 5.1 and 5.2.

The quantities of irrigation water diverted to the agriculture lands during 1964 and 1965 are tabulated in Tables 6.2 and 6.3. These quantities were estimated in accordance with the procedure for Colorado described in the previous section. Estimated irrigation diversions for all subbasins used in this study are listed by Appendix E. Transfers of water either to or from the subbasin (imports and exports) and groundwater pumpage are not significant in the White River drainage. These processes were, therefore, not included in the model.

It was postulated in Chapter IV that salt is contributed to the waters of the Upper Colorado River basin through an interchange process between surface and subsurface waters. Influent flow from the main stream enters the groundwater basin, and, under conditions of equilibrium, an equal volume of effluent flow enters the stream in a lower reach of the channel. The salinity concentrations of the effluent waters are assumed to be equal to those of the groundwater. In this study the rate of interchange flow for each subbasin of the Upper Colorado was expressed empirically as a proportion of the flow rate at a particular point in the main surface channel. For the White River system this relationship was based on the surface flows at Watson, Utah. Estimation of the rate of interchange then entailed determining a percentage figure from either Equation 4.14 or Figure 4.3. The salt flow rate due to the interchange phenomenon was then computed by Equation 4.15 as a function of the percentage interchange, basin outflow, and groundwater salinity concentration. Total basin outflow rates for both water and salt, and the rate of interchange expressed as a percentage of total monthly water flow are tabulated in Tables 6.2 and 6.3 for the years 1964 and 1965.

Several other single valued parameters, such as soil moisture capacity, M_{cs}, the specific rate of snowmelt, ks, and various correlation coefficients, are required in the model. These parameters are assumed to be fixed for a given subbasin. Thus initial values are estimated from available data and are further refined during model verification. The values of these parameters that were established for the White River subbasin model are tabulated in Table 6.4. This table also lists required initial conditions for each of the two years and delay times associated with flow in the groundwater system. As indicated in Chapter V, end-of-year values of certain functions are used as initial values for corresponding functions in the subsequent year. Groundwater delays are determined through the verification process, and in the case of the White River subbasin (Table 6.4), one delay corresponds to the time required for deep percolating flows to appear at the outflow gage. The other delay is associated with the average length of time required for water within the groundwater system to leave the basin as subsurface flow.

Computer output from the verified model of the White River subbasin is shown by Figure 6.11. The model was calibrated with 1964 data and tested over the 12-month period of 1965. In Figure 6.11 a comparison is made between computed and observed values for both water discharge in acre-feet, and salt discharge in tons at a monitoring station near Watson, Utah. On an annual basis the differences between the computed and observed values of discharge do not exceed about 3 percent for water and 7 percent for salt. On a monthly basis discrepancies are slightly higher, but in general, good fits were obtained for both the water and salt discharge functions. As a point of interest, the agreement between the computed and observed salt outflow rates for the White River subbasin proved to be among the least accurate of those obtained for all of the subbasins of the Upper Colorado River drainage.

Additional output functions from the model of the White River subbasin are shown by Figures 6.12, 6.13, and 6.14. Although these plots are specific to the White River system for a particular year (1964), they are representative of the kind of information that is available from the simulation model. Figure 6.12 illustrates

Table 6.4. Single constant input parameters or coefficients for the White River subbasin.[a]

Symbol	Description	Value
k_u	coefficient relating the rate of unmeasured inflow to a system to a measured inflow rate (WHITE RIVER)	0.25
k_a	coefficient relating the rate of unmeasured surface inflow to the precipitation rate	0.55
k_b	coefficient relating the rate of unmeasured surface inflow to the rate of melting snow storage	3.15
k_c	coefficient relating the rate of unmeasured groundwater runoff to a surface runoff rate	0.0
k_s	a constant applied in the computation of snowmelt rate	0.20
Eff	water conveyance and application efficiency	65%
M_{es}	limiting value of available soil moisture applied in computation of evapotranspiration	2.0 inches
M_{cs}	available soil moisture storage capacity	6.0 inches
k_d	average percentage of total outflow leaving as subsurface flow	4%
C_g	average salinity concentration within the groundwater basin	1600 ppm
C_s	factor which increases the average salinity concentration of the surface inflow as it returns from the irrigated lands	1.25
C_{ga}	average salinity concentration within the groundwater system of the agriculture area	400 ppm
C_{og}	average salinity concentration of subsurface water leaving the system at the outflow point	1900 ppm
n	intercept on y-axis of log-log plot of percent interchange and flow when the latter equals 1.0 cfs (Equation 4.4)	1400
m	slope of line on log-log plot relating percent interchange and flow (Equation 4.4)	-0.62
Pot 5	threshold at which the precipitation correlation becomes effective	2.13 inches
Pot 21	initial condition for snow storage	1.5 inches (1964) 3.7 inches (1965)
Pot 24	initial condition for soil moisture content	3.0 inches (1964) 5.7 inches (1965)
Pot 28	initial condition for deep percolating flows	0.08 inches (1964) 0.08 inches (1965)
Pot 30	initial condition for groundwater outflow	0.02 inches (1964) 0.02 inches (1965)
Delay A	time of delay before deep percolating flows appear at outflow point	3½ months
Delay B	time flows within the system are delayed before leaving the basin as subsurface outflow	2½ months

[a] All values expressed in inches refer to depth over the irrigated land.

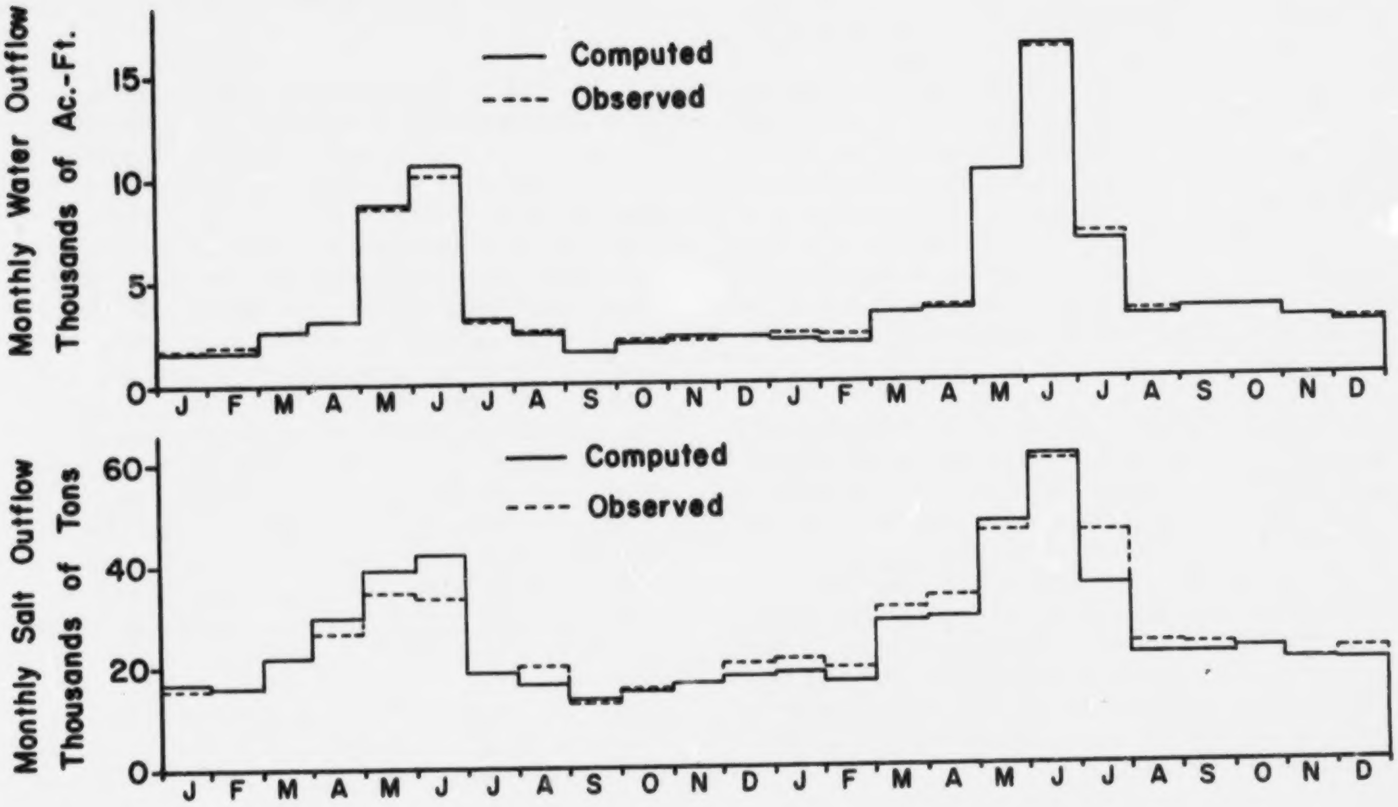


Figure 6.11. Comparison of computed and observed monthly discharge of water and salt from the White River basin for 1964 and 1965.

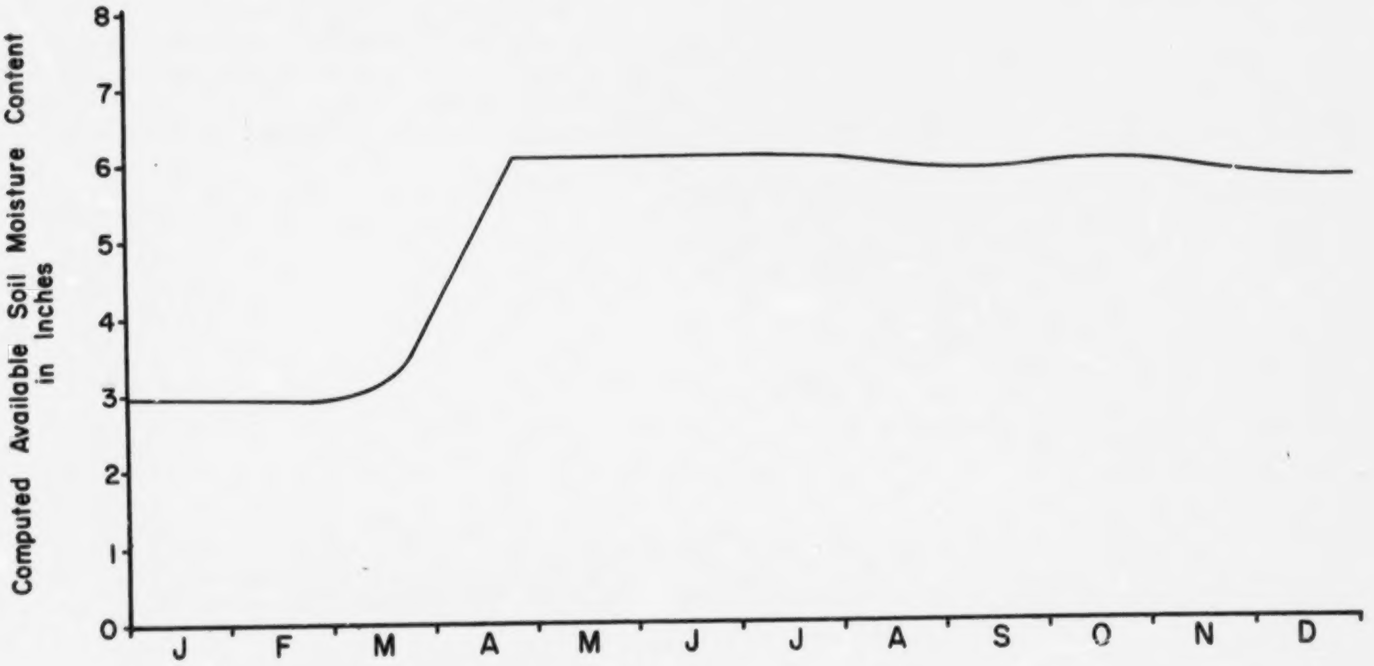


Figure 6.12. Computed available soil moisture in the agriculture area of the White River subbasin for 1964.

the time variation of the soil moisture level in the plant root zone of the agricultural area in the subbasin. Snowmelt produces the sharp rise in soil moisture storage during April. In early May the capacity is reached, and irrigations and fall rains are sufficient to virtually maintain this level throughout the remainder of the year. In subbasins where adequate supplies of irrigation water are not available, soil moisture levels might not reach capacity during the irrigation season. The computed average soil moisture storage at the end of December 1964 (5.7 inches) for the White River subbasin was used as the initial soil moisture level at the beginning of the 1965 modeling year.

Deep percolating waters from the agricultural lands are assumed to move through the groundwater basin, eventually to appear as effluent flow in the main surface channel of the subbasin. The computed discharge function for this effluent flow as computed by the model of the White River basin is shown by Figure 6.13. These flows were delayed by 3 1/2 months (3 1/2 seconds computer time) from time of percolation to time of outflow from the groundwater system. The computed plot of deep percolating salt flow is similar in shape to the curve of Figure 6.13, and differs only in the scale of the ordinate values.

The rate of subsurface flow from the subbasin was computed at Watson, Utah, and is shown by Figure 6.14. A period of 2 1/2 months was used as the average time required for water to move through the groundwater basin and leave as subsurface outflow.

A schematic diagram of the estimated average annual hydro-salinity flow system of the White River subbasin is shown by Figure 6.15. This flow diagram was developed by weighting computer output for 1964 and 1965 with respect to long-term averages of temperature, precipitation, and surface water flows. Needless to say, certain judgment factors were also involved in this procedure.

The average annual evapotranspiration loss from the cropland indicated by Figure 6.15 is equivalent to 2 feet per acre of irrigated land, a somewhat higher value than suggested by some sources, but comparable to that given by others. Further, the relative salt contributions from agricultural and natural sources differ somewhat from those reported by other studies. For example, Iorns et al. (1965), estimate that the salt load attributable to man's agricultural activity in the White River basin is 5.5 tons per acre irrigated, whereas this study indicates a corresponding value of less than 1.0 ton per acre irrigated. The difference may be attributed in part to the approach taken by this study in which an attempt was made to simulate the major processes of the hydro-salinity flow systems with respect to both space and time. With regard to the groundwater system existing within the White River basin, Iorns et al. (1965) state that large groundwater reservoirs in the permeable formations of the White River Plateau produce good base flows in the river even during periods of low precipitation. The large natural salt contribution indicated by Figure 6.15 might result from these high base flows. Because of the success achieved in simulating the natural salt increase in each of the subbasins of the Upper Colorado River by means of an empirical relationship, the results reported for the White River subbasin appear reasonably valid. However, it is strongly recommended that additional study and research be directed towards investigating the natural salt loading that occurs within the Upper Colorado River basin.

The general procedure outlined in this Chapter for the development of a model of the White River subbasin was repeated for each of the 40 subbasins considered in this study. Pertinent information on the model for each subbasin is contained in the appendices of this report.

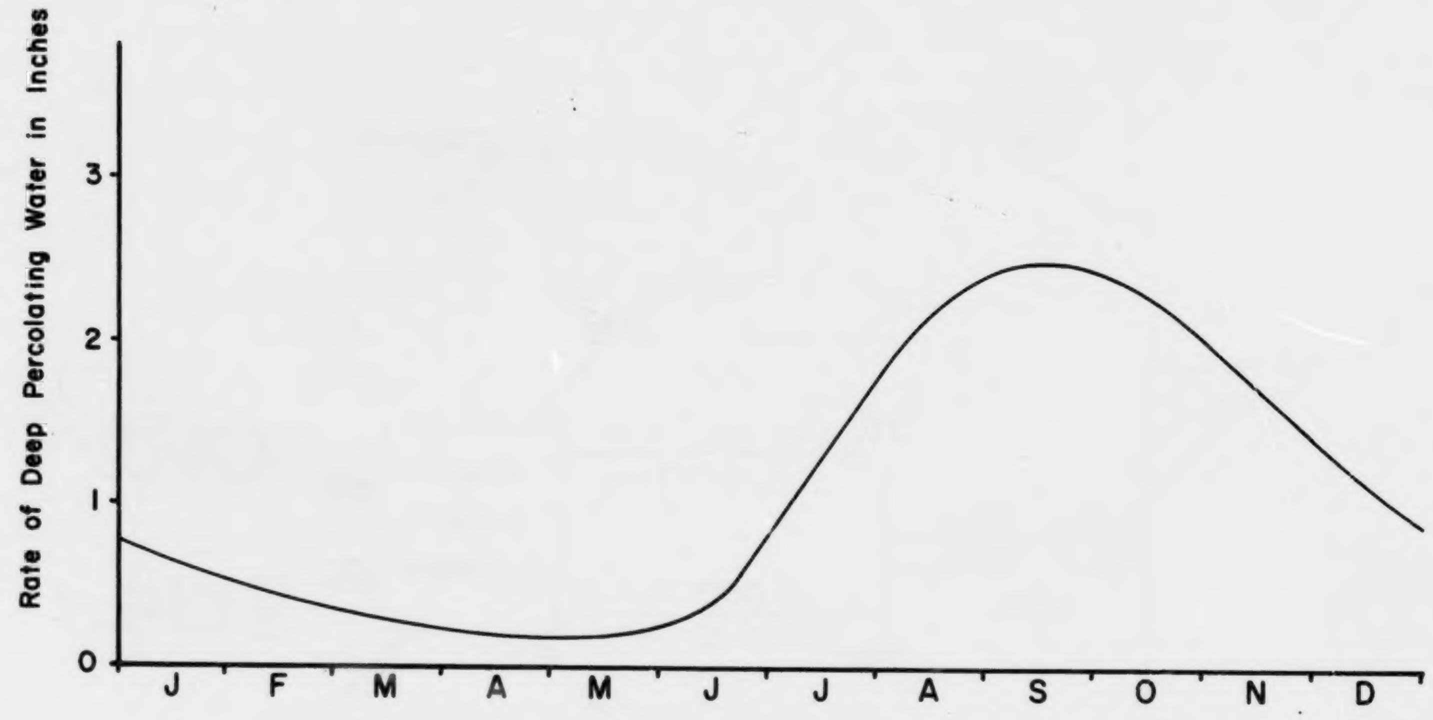


Figure 6.13. Rate of deep percolating flow of water from agriculture area of the White River subbasin for 1964.

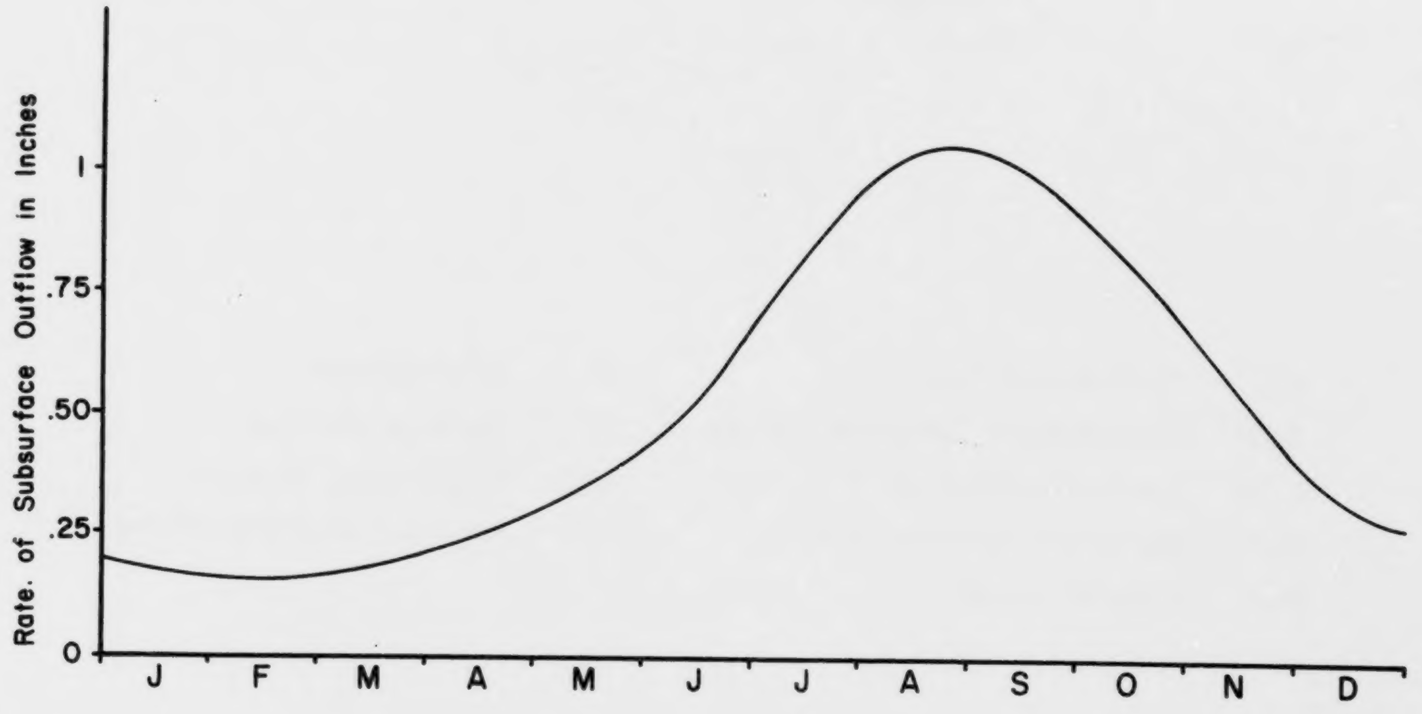
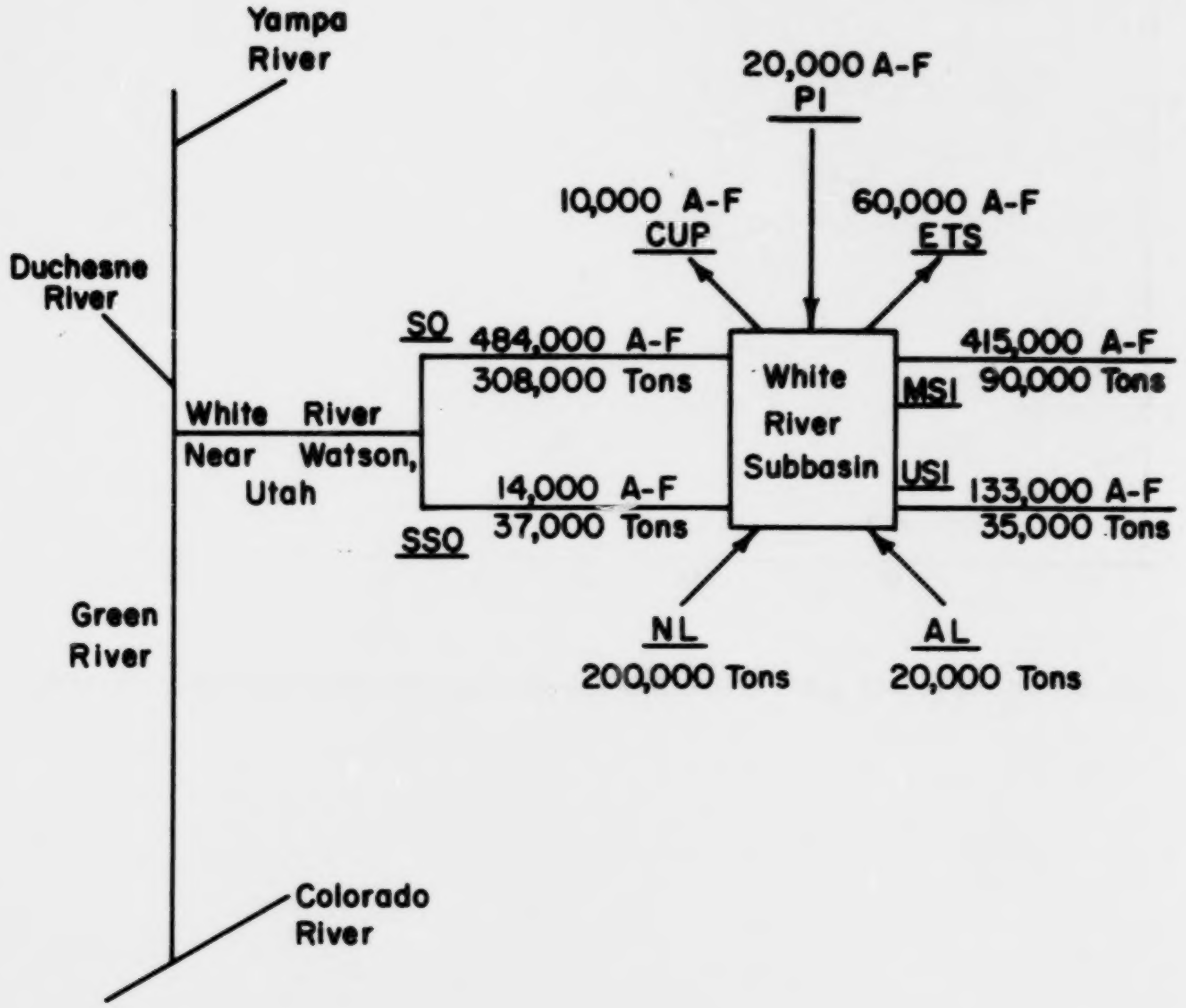


Figure 6.14. Rate of subsurface outflow of water at outflow monitoring points of the White River subbasin for 1964.


Yampa River
20,000 A-F
PI
10,000 A-F
CUP
60,000 A-F
ETS
Duchesne River
SO
484,000 A-F
308,000 Tons
White River Subbasin
415,000 A-F
MSI
90,000 Tons
White River
Near Watson, Utah
14,000 A-F
37,000 Tons
SSO
USI
133,000 A-F
35,000 Tons
Green River
NL
200,000 Tons
AL
20,000 Tons
Colorado River

AL	Agricultural Load	PI	Precipitation
CUP	Phreatophyte Consumptive Use	SO	Surface Outflow
ETS	Evapotranspiration from Soil	SSO	Subsurface Outflow
MSI	Measured Surface Inflow	USI	Ungaged Surface Inflow
NL	Natural Load		

Figure 6.15. Schematic diagram of estimated average annual hydro-salinity flow system of the White River basin.

CHAPTER VII

SYNOPSIS OF THE MODEL SUBBASINS WITHIN THE UPPER COLORADO RIVER DRAINAGE

In order to incorporate spatial resolution into the hydro-salinity model of the Upper Colorado River basin, the entire drainage area was divided into 40 subareas or subbasins (Figure 6.1). Of these, 18 subbasins lie within the Green division, 14 are within the Grand division, and 8 are included in the San Juan division. The same general hydro-salinity model was applied to each of these subbasins and characterized for each through a verification procedure. The modeling technique that was applied to each subbasin is outlined in Chapter VI, in which the White River subbasin within the Green division was used as an illustrative example. Each of the other subbasins was treated in the same way and given the same careful considerations as was the White River subbasin. In this chapter specific characteristics of each subbasin are briefly described. The hydrologic area, geographic location of the monitored inputs, and the distribution of the agricultural lands for each subbasin are illustrated in Appendix A. The hydrologic and salinity inputs were scaled according to the irrigated land area contained within each subbasin (Appendix B). The meteorological stations, weighting factors, and data for the years modeled are listed in Appendix C. Hydrologic and salinity input stations, corresponding to those depicted in Appendix A, are listed in Appendix D. The digital computer program utilized for estimating missing records and for extending records is also contained in Appendix D. The digital computer program that was used for estimating needed salinity concentrations of input streams is included in Appendix G. Other relevant data are presented in Appendices E and F. The model parameters which characterize the general hydro-salinity model for a particular subbasin are listed by Table 6.4. The values of these parameters were established for each subbasin through the verification procedure, and these are tabulated in Appendix H.

Green Division

New Fork River subbasin

Both hydrologic and salinity data within this subbasin are sparse. Irrigation diversion rates to the agricultural lands have not been recorded. These rates were estimated during the model verification procedure, with consideration being given to recorded diversions in comparable basins. The few available salinity measurements indicated a generally low level of total dissolved solids in basin inflows. The digital computer program for estimating salinity (Appendix G) was utilized extensively. A low irrigation efficiency (55 percent) appears to prevail although the soil moisture reservoir is generally adequate to maintain full consumptive use throughout the growing season. Ungaged water inflow rates were estimated from Equation 3.4 in which q_{is} (m) was the total of all gaged inflow rates. The area occupied by phreatophytes was estimated from field trip observations, maps, and model verification. Output from the model indicates that more than 7 percent of the total subbasin outflow occurs as subsurface flow. The incremental salt load which was added within the subbasin as a result of the interchange phenomenon was computed as a function of the surface water outflow. Unlike most subbasins within the New Fork River drainage, the incremental salt load from natural sources is apparently maintained at a relatively constant level throughout the year. Comparisons between the computed and observed discharge rates for both water and salt for the years 1965 and 1966 are shown by Figure H-1. Changes in the agricultural component of the system were reflected in the computed outflow functions for water and salt.

Green River above La Barge, Wyoming, subbasin

Both hydrologic and salinity data for the Green River above La Barge are very limited. Because records of irrigation water diversions to agricultural lands were not available, rates were estimated during the verification procedure with consideration being given to recorded diversions in comparable basins. New Fork River, the largest tributary to the Green River in this subbasin, is the only input source having complete salinity data. The digital program in Appendix G was used to estimate the salinity concentrations for the Green River at Warren Bridge during the model period. Ungaged surface inflow rates were estimated by Equation 3.4, in which the recorded flows of North Piney Creek near Mason, Wyoming, represented the term q_{is}(m). Phreatophyte acreage was estimated from field trip observations, maps, and model verification. According to the model results, only a small proportion (1.2 percent) of the total basin outflow leaves as subsurface flow beneath the gage. The natural salt load increment within the system as a result of the interchange phenomenon was computed as a function of the surface water outflow from the subbasin. Computed and observed outflow rates for both water and salt during the years 1965 and 1966 are illustrated by Figure H-2. Changes within the agricultural component of the model produced barely discernible effects on the computed outflow functions.

Green River above Fontenelle Reservoir subbasin

This subbasin on the main stem of the Upper Green River is in the high, arid plateau country of western Wyoming. This subbasin is small in comparison to the others. Fontenelle Reservoir inundates most of the valley floor, leaving only a few acres in the drainage of Fontenelle Creek for agricultural production. The model is, therefore, very insensitive to changes within the agriculture system. It is estimated that an appreciable quantity of subsurface flow (approximately 25,000 acre-feet annually) enters the subbasin from the adjacent upstream area. The model indicated no discharge from the subbasin as subsurface flow. This result was expected because of the barrier created by Fontenelle Dam. All surface water inflow to the subbasin is measured. Perhaps because of the short length of the main river channel within the area, no salt load was indicated from natural sources through the interchange process. Discharge rates are controlled by the operation of Fontenelle Reservoir. In the model, additions to or depletions from reservoir storage were treated as corresponding basin inputs or outputs. Utilizing an exponential expression, changes in bank storage in the reservoir were considered by the model as a function of changes in reservoir storage. Studies suggest that substantial volumes of water can be stored by the soils which surround Fontenelle Reservoir. As with all reservoirs in this study, Fontenelle Reservoir was treated as a point of discontinuity in modeling the salinity flow system. Additional work is needed in order to develop a satisfactory model of salt flow through storage reservoirs, especially those from which releases occur at various depths. Figure H-3 illustrates a comparison between computed and observed outflows from the basin for the years 1965 and 1966. In September 1965 a dam failure produced a large drawdown in Fontenelle Reservoir. Under these conditions, Figure H-3 clearly indicates the effects of bank storage upon the outflow hydrograph from the subbasin.

Big Sandy Creek subbasin

The Big Sandy Creek subbasin contributes to the Green River a portion of the runoff that originates in the southern section of the Wind River mountain range. Two reservoirs, Big Sandy Creek and Eden, control and regulate most of of the basin inflow. The relatively small portion of ungaged inflow was estimated by correlation with the melting snow rate. The available intermittent salinity measurements of the inflowing waters indicated a generally low level of dissolved solids. Missing salinity values were estimated from the existing data. Outflow salinity levels were monitored at the reservoir outlets and showed little variation. Canal diversion rates, land areas, crop species, and other needed data were available since most of the lands are serviced by the Bureau of Reclamation. A low soil moisture capacity (5 inches) exists in this subbasin, and low levels of irrigation efficiency (54 percent) appear to prevail. Phreatophyte density and acreage were estimated from field observation and model verification studies. Development of the hydro-salinity flow model was complicated by the large groundwater system and high groundwater salinity concentrations (2200 ppm) within the basin. Almost one third of the total outflow occurs beneath the surface. The model indicated a high level of sensitivity to changes within the agricultural segment of the system. Most of the salt load leaving the subbasin originates from natural and diffused sources within the system. The estimated natural salt load, exclusive of that contributed through the activities of man, was computed as a function of the water discharge rate from the basin. The accuracy with which the simulation model describes the flow systems is indicated by Figure H-2 which compares computed and simulated outflow rates for water and salt for the years 1962 and 1963.

Green River above Green River, Wyoming, subbasin

This subbasin is directly below Fontenelle Reservoir on the main stem of the Green River in the high plateau country of Wyoming. The inputs to the system are well defined, consisting of the recorded outflows from Fontenelle Reservoir and Big Sandy Creek, and the computed subsurface outflow from the latter subbasin. Estimates of ungaged inflow were correlated with the rate of snow melt (Equation 3.4). The phreatophyte acreage was estimated in the same manner as for the other subbasins in Wyoming. The only notable increase in salt loading occurs from natural sources and was estimated on the basis of the interchange process. No subsurface flow occurs from the basin. Figure H-5 illustrates comparison between observed and computed outflows of water and salt from the basin for the years 1964 and 1965. The model indicated no sensitivity to changes within the agricultural segment of the system.

Blacks Fork River subbasin

Most of the water that flows into the Blacks Fork River subbasin originates from the north slope of the Uinta Mountains, and most of these flows are recorded. Both the precipitation and snowmelt components of Equation 3.4 were required to define the relatively small ungaged inflow to the basin. The monthly outflow of water from the basin is extremely variable (Figure H-6), with the major portion of the total annual discharge occurring during spring runoff period. Records obtained from a power company which operates Lake Viva Naughton on the Hams Fork River were used to estimate the time distribution of water flows from this tributary. No records were available of water diversion rates to the agricultural area. These values were estimated by considering the carrying capacities of the canals and the quantities of water available for diversion within the sources. As with other subbasins in Wyoming, the phreatophyte acreage was estimated from a field inspection and a study of available maps. The model indicated a moderately high irrigation efficiency of 62 percent, which probably can be explained by the extensive rediversion of return flows. Irrigation water is generally in short supply as indicated by the depletion of the available water in the plant root zone for both model years. Most of the water inputs to the Blacks Fork area are well monitored insofar as salinity measurements were concerned, but those on Hams Fork are not. The digital computer program of Appendix G, therefore, was used for estimating salinity concentrations on the Hams Fork River. More than half of the salt load added within the subbasin appears to originate from natural sources. This contribution was estimated from the interchange process as a function of the rate of water discharge from the subbasin. Approximately 10 percent of the total water discharge from the subbasin occurs as subsurface flow. Comparisons between computed and observed discharge functions for both water and salt for the years 1964 and 1965 are shown by Figure H-6. Because of the comparatively low streamflow rates during the summer months and the rather extensive irrigated area within the subbasin, the model was very sensitive to changes within the agricultural component of the system.

Green River above Flaming Gorge Dam subbasin

This subbasin is on the main stem of the Green River with most of the area lying in southwestern Wyoming and the remainder in Northeastern Utah. The only significant agriculture in the subbasin is on Henry's Fork, and the effects of farming practices on the outflows of both water and salt from the subbasin are, therefore, minor. A small quantity of water enters the basin as subsurface flow from the Blacks Fork River basin. The model indicated no subsurface outflow from the subbasin. This result was expected because of the barrier created by Flaming Gorge Dam. Ungaged water input to the subbasin was small and was estimated by Equation 3.4, in which the term q_{is} (m) represented the combined flows of the Middle Fork of Beaver Creek near Lonetree, Wyoming, and Elkhead Creek near Clark, Colorado. Most of the salinity inputs to the basin also were monitored. Where data were lacking, the digital computer programs in Appendices D and G were used to provide estimates. The model indicated no significant increase within the subbasin in natural salt loading. Again, this result was expected because the main river channel is covered for most of its length by the reservoir. Outflow from the subbasin depends primarily on the operation of Flaming Gorge Reservoir. Bank storage apparently has a significant effect on water levels in Flaming Gorge Reservoir, and was included in the hydrologic model as an exponential function of the change in reservoir storage. For the salinity component of the model the reservoir was treated as a point of discontinuity. Figure H-7 illustrates a comparison between observed and computed outflows from the subbasin for the years of 1965 and 1966.

Little Snake River subbasin

This subbasin lies in the states of Wyoming and Colorado with the Continental Divide as the boundary in the upper reaches of the drainage area. The outflow hydrographs of Figure H-8 reflect the extremely variable flow conditions. At times there is essentially no surface outflow. However, because of the high permeability of the alluvium, groundwater flow is rapid and an estimated 22,000 acre-feet per year leave the system as subsurface flow. During the model verification process groundwater delay times of two months or less were obtained (Table H-1). Nearly all of the inflows are monitored and Equation 3.4 was used to estimate the remaining small volume of ungaged inflows on the basis of the recorded flows of Savery Creek near Savery, Colorado. Meager records of inflow salinity concentrations were available on several streams (Appendix D), and the digital computer program of Appendix G was used to estimate missing values. The salinity concentrations of all the ungaged surface inflows were assumed identical to the measured values for Savery Creek near Savery, Colorado. Canal diversions were unavailable for the portion of the subbasin lying within Wyoming, but these were estimated on the basis of the time and spatial distributions recorded in the Colorado portion of the subbasin. Similarly, phreatophyte acreage for the entire subbasin was estimated on the basis of information available from Colorado. The sensitivity of the model to changes in irrigation practices and efficiency is significant. In the late summer months, water supplies are often short, whereas in the spring months the supply is always more than adequate. As a result, soil moisture supplies become depleted during the summer and evapotranspiration rates are reduced. The incremental salt load added within the subbasin is largely the results of the interchange phenomenon which is expressed in the model as a function of water outflow rates.

Yampa River subbasin

The Yampa River derives most of its water from the high mountains of the continental Divide in northern Colorado. More than one-third of the total water inflow is unmeasured. This component was estimated by Equation 3.4 using computed movement rates and recorded flows of the Elk River at Clark, Colorado. Salinity concentrations as required were estimated by the computer program of Appendix G. Average annual flow rates are estimated to be 88,000 acre-feet of water and

88,000 tons of salt. The quantity of subsurface flow leaving the subbasin is large. Model studies indicated that (1) the system is sensitive to changes within the agricultural component, and (2) a high proportion of the total salt load added within the subbasin is attributable to the irrigation activities of man. Computations involving the natural salt loading process were based on surface water outflow rates from the subbasin. Because of an abundance of water for irrigation in most of the subbasin, the soil moisture capacity in the plant root zone is full most of the time, and the average irrigation efficiency is, therefore, low (50 percent). Computed and measured output functions for both water and salt are shown by Figure H-9.

Green River above Jensen, Utah, subbasin

This subbasin is on the main stem of the Green River. Because nearly all inflows to the basin are gaged, both the hydrology and the salinity flow systems are well defined, and no correlation processes were required. Flaming Gorge Dam prevents any subsurface inflows along the main river channel. Satisfactory verification of the model was found to depend upon the inclusion of the simulated subsurface flows passing the gages at the Little Snake near Lilly, Colorado, and the Yampa River near Maybell, Colorado (Figure 7.1). According to the model results, no appreciable salt loading occurs within this subbasin from the interchange phenomenon. This result was anticipated because the main channel is short and through most of its length is confined to a narrow and rocky gorge. The subsurface outflow from the basin was computed to be less than 1 percent of the total outflow. A comparison between computed and observed output functions is shown by Figure H-10. The model output showed no significant response to changes in the agricultural component of the system.

Ashley Creek subbasin

Although Ashley Creek discharges directly into the main stem of the Green River, the effects of the hydrologic and salinity outflows from this tributary upon the total flows of the Green River are minor. The major inflow to the modeled area occurs as measured outflow from offstream storage in the Steinaker Reservoir. The relatively small ungaged surface inflow component was estimated by correlation with precipitation and snowmelt (Equation 3.4). Ungaged subsurface inflow rates were estimated by correlation with the total measured inflow to the basin (Equation 3.6), and by then applying a delay of approximately 5 1/2 months. The waters of Ashley Creek are extensively used for irrigation within the subbasin. Most irrigation diversions are measured, although some unmeasured flows are diverted to fill secondary water rights during periods of high spring runoff, and these diversions were estimated for input to the model. The discharge of two canals that divert water from above the outflow gage to lands below this point was treated as exports from the subbasin. According to the model, less than 1 percent of the total basin outflow constitutes subsurface flow. Average groundwater salinity concentrations within the subbasin were estimated to be about 2500 ppm. The salt load originating from the interchange phenomenon was estimated as a function of the surface water discharge rate from the area. A significant portion of the total salt load from within the subbasin (approximately 12,000 tons per year) was attributed to the effects of irrigation. The average irrigation efficiency of 65 percent was estimated through the model verification studies. Computed and observed outflow functions for both water and salt are compared in Figure H-11. As expected, output from the simulation model was highly sensitive to changes within the agricultural component of the system.

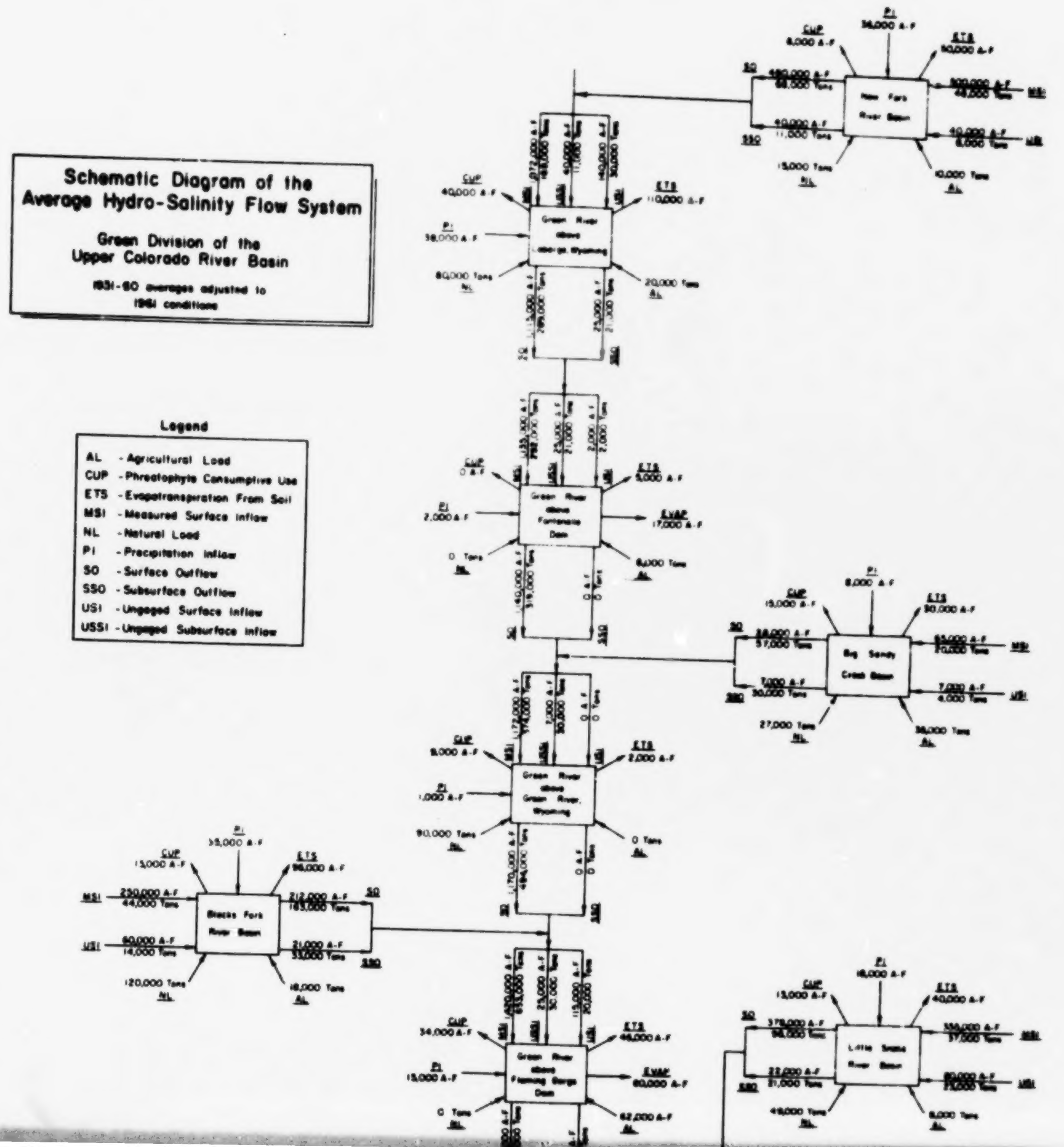
Duchesne River above Duchesne, Utah, subbasin

This subbasin lies in the upper portion of the Duchesne River system and is drained primarily by the Duchesne and the Strawberry Rivers. Both the hydrologic and salinity inflows to the subbasin are fairly well defined, although the digital computer programs presented in Appendices D and G were both utilized. In particular, it was necessary to estimate salinity concentrations within the Strawberry drainage area. Ungaged inflows to the subbasin were estimated by correlation procedures using Equation 3.4. Some of these estimates were based on the measured flows of Water Hollow Creek near Fruitland, Utah. Exports from the subbasin are by way of the Duchesne Tunnel into the Provo River, and the Rocky Point Canal which supplies irrigation water for lands lying downstream from the subbasin. Although subject to some question, recorded data on water diversions for irrigation were used in the model verification. Irrigation flows maintained a near capacity soil moisture level throughout most of the growing season. The average irrigation efficiency was found to be about 50 percent. The model also suggested that the practice of irrigation contributes only a small part of the total salt outflow from the subbasin. As a matter of fact, the model was found to be very insensitive to changes within the agricultural component of the system. It was estimated that the interchange phenomenon contributes approximately one half of the recorded salt outflow from the subbasin. This natural salt loading was treated as a function of the basin surface outflow. Subsurface flow constitutes approximately 10 percent of the total outflow from the basin. Figure H-13 illustrates computed and observed outflows of water and salt from the basin for the years 1965 and 1966.

Duchesne River above Randlett, Utah, subbasin

This subbasin encompasses the lower part of the Duchesne River and its tributaries, most of which drain the south side of the Uinta Mountains. The hydrologic inputs are well defined and only the snow correlation component of Equation 3.4 was needed to estimate the ungaged water input to the subbasin. The salinity inputs

Figure 7.1. Schematic diagram of the average hydro-salinity flow system, Green River division.


New Fork River Basin
PI 36,000 A-F
CUP 8,000 A-F
ETS 90,000 A-F
SO 480,000 A-F 88,000 Tons
SSO 40,000 A-F 11,000 Tons
MSI 500,000 A-F 48,000 Tons
USI 40,000 A-F 8,000 Tons
15,000 Tons NL
10,000 Tons AL
Green River above Labarge, Wyoming
CUP 40,000 A-F
PI 38,000 A-F
ETS 110,000 A-F
80,000 Tons NL
20,000 Tons AL
MSI 1,072,000 A-F 188,000 Tons
USSI 40,000 A-F 11,000 Tons
USI 140,000 A-F 30,000 Tons
SO 1,113,000 A-F 299,000 Tons
SSO 25,000 A-F 21,000 Tons
Green River above Fontenelle Dam
CUP 0 A-F
PI 2,000 A-F
ETS 5,000 A-F
EVAP 17,000 A-F
0 Tons NL
6,000 Tons AL
MSI 1,133,000 A-F 292,000 Tons
USSI 25,000 A-F 21,000 Tons
USI 2,000 A-F 2,000 Tons
SO 1,140,000 A-F 319,000 Tons
SSO 0 A-F 0 Tons
Big Sandy Creek Basin
PI 8,000 A-F
CUP 15,000 A-F
ETS 30,000 A-F
SO 38,000 A-F 57,000 Tons
SSO 7,000 A-F 30,000 Tons
MSI 85,000 A-F 20,000 Tons
USI 7,000 A-F 4,000 Tons
27,000 Tons NL
36,000 Tons AL
Green River above Green River, Wyoming
CUP 9,000 A-F
PI 1,000 A-F
ETS 2,000 A-F
90,000 Tons NL
0 Tons AL
MSI 1,172,000 A-F 374,000 Tons
USSI 7,000 A-F 30,000 Tons
USI 0 A-F 0 Tons
SO 1,170,000 A-F 494,000 Tons
SSO 0 A-F 0 Tons
Blacks Fork River Basin
PI 35,000 A-F
CUP 15,000 A-F
ETS 96,000 A-F
MSI 250,000 A-F 44,000 Tons
USI 60,000 A-F 14,000 Tons
SO 212,000 A-F 183,000 Tons
SSO 21,000 A-F 33,000 Tons
120,000 Tons NL
18,000 Tons AL
Green River above Flaming Gorge Dam
CUP 34,000 A-F
PI 15,000 A-F
ETS 46,000 A-F
EVAP 60,000 A-F
0 Tons NL
62,000 A-F AL
MSI 1,420,000 A-F 833,000 Tons
USSI 25,000 A-F 30,000 Tons
USI 115,000 A-F 20,000 Tons
Little Snake River Basin
PI 18,000 A-F
CUP 13,000 A-F
ETS 40,000 A-F
SO 379,000 A-F 98,000 Tons
SSO 22,000 A-F 21,000 Tons
MSI 350,000 A-F 37,000 Tons
USI 80,000 A-F 25,000 Tons
49,000 Tons NL
8,000 Tons AL

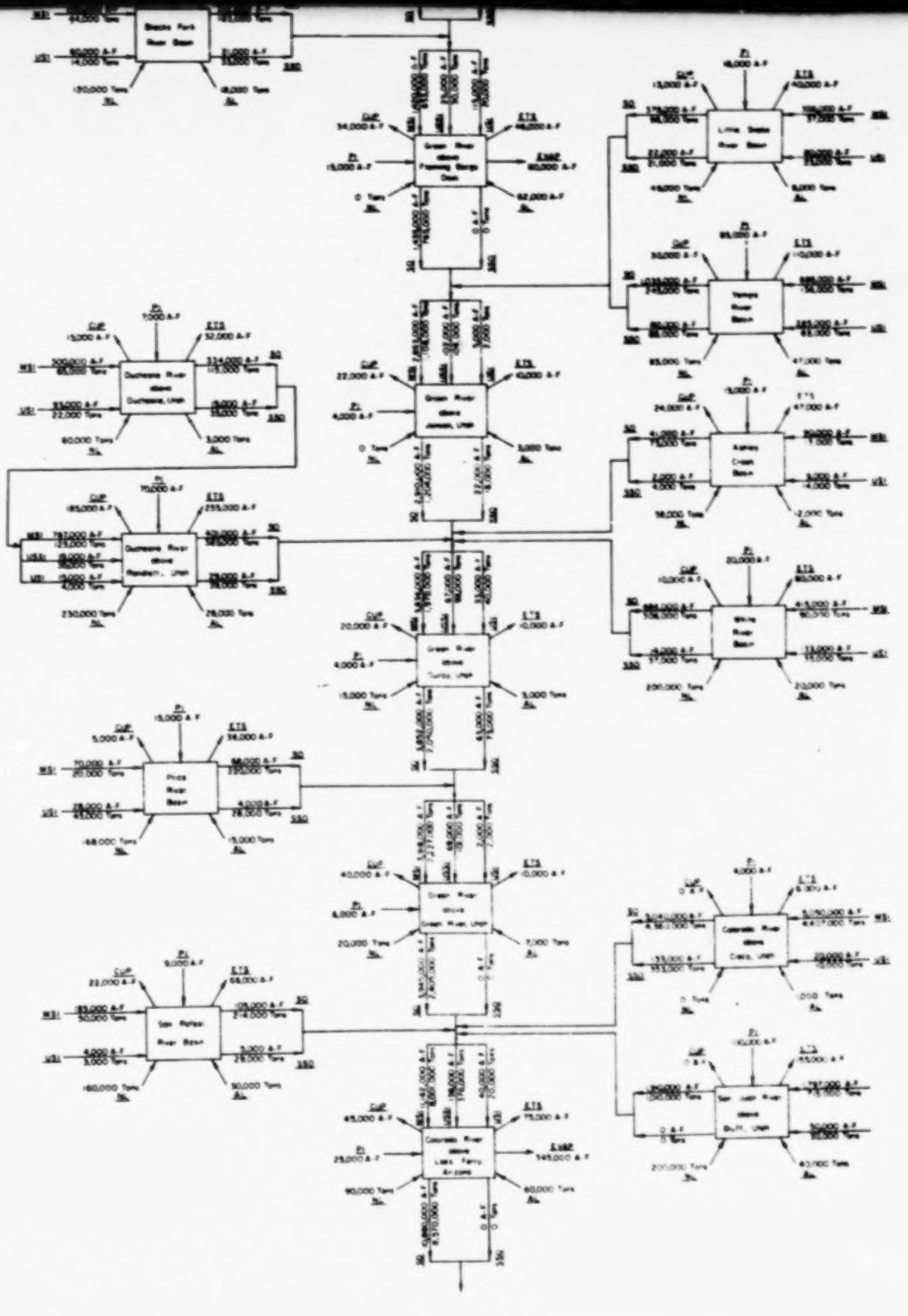
Schematic Diagram of the Average Hydro-Salinity Flow System

Green Division of the
Upper Colorado River Basin

1931-60 averages adjusted to
1961 conditions

Legend

AL - Agricultural Load
CUP - Phreatophyte Consumptive Use
ETS - Evapotranspiration From Soil
MSI - Measured Surface Inflow
NL - Natural Load
PI - Precipitation Inflow
SO - Surface Outflow
SSO - Subsurface Outflow
USI - Ungaged Surface Inflow
USSI - Ungaged Subsurface Inflow


Green River above Flaming Gorge Dam
Little Snake River Basin
Yampa River Basin
Green River above Jensen, Utah
Ashley Creek Basin
Duchesne River above Duchesne, Utah
Duchesne River above Randlett, Utah
White River Basin
Price River Basin
Green River above Green River, Utah
San Rafael River Basin
Colorado River above Cisco, Utah
San Juan River above Bluff, Utah
Colorado River above Lees Ferry, Arizona

also have been well monitored. This subbasin involves a large agricultural area, and the effect of irrigation on the outflow of both water and salt is pronounced. The model was exceptionally sensitive to changes in all of the parameters related to irrigation. The model includes Rocky Point Canal near Duchesne, which imports water into the subbasin, and the Pleasant Valley and Pelican Lake Canals which export water from the subbasin. Small reservoirs within the subbasin such as Lake Boron and Montery Creek, also were considered. The rather high natural salt loading within the subbasin from the interchange phenomenon was estimated on the basis of surface water outflow. The model indicated that approximately 10 percent of the outflows of both water and salt from the subbasin occurs beneath the surface. The agreement achieved between computed and measured outflows during the model verification studies is illustrated by Figure H-14.

White River subbasin

The White River subbasin has been discussed in considerable detail in Chapter VI where it was used to illustrate the manner in which all of the subbasins were modeled. Agreement achieved between computed and observed outflows from the subbasin is illustrated by Figure H-15.

Green River above Ouray, Utah, subbasin

This subbasin incorporates the confluences of the Green River with the Duchesne River, White River, and Ashley Creek. The inputs to this subbasin consist of recorded flows and computed groundwater outflows from the adjoining subbasin. Salinity concentrations are equally well defined. A small volume of ungaged water that apparently originates within the basin was estimated using only the component of Equation 3.4 that requires a measured flow, and records from Minnie Maud Creek near Myton, Utah, were used for this purpose. The estimated subsurface water outflow is small, being less than 1 percent of total basin discharge. Because of the relatively small area of agricultural land in the basin, the model was very insensitive to changes within the agricultural component of the system. The estimated increase in the salt load from the interchange phenomenon was negligible. It is recognized, however, that some salt undoubtedly originates in the basin from this source. Observed and computed outflow functions are compared in Figure H-12.

Price River subbasin

Outflow from the Price River subbasin discharges directly into the lower Green River in eastern Utah. Verification of this subbasin was difficult, primarily because of the lack of adequate inflow data. Ungaged surface water inflows were estimated from Equation 3.4 excluding the precipitation component and using the recorded flows of Willow Creek near Castle Dale. The flows of this stream reflect the hydrologic effects of the high intensity, short duration thunderstorms within the area. Correlation procedures were applied to estimate salinity records as required for input streams. The ungaged groundwater inflow was estimated by correlation with the total surface inflow to the basin delayed by one and one half months. The salinity concentration of the subsurface inflow was assumed to be relatively constant between 950-1000 ppm. Model studies indicated that both the hydrologic and salinity flow systems are sensitive to changes within the agricultural system. The model parameters associated with the agricultural system are indicated by Table H-1 (Appendix H), and are typical of those of other subbasins. Model output suggested that soil moisture supplies reach low levels at times during the growing season. The particularly low diversion rates of water during 1964 probably resulted in deposition of salt in the soil profile during that year. The verification process suggested a smaller area of phreatophytes than was anticipated on the basis of previous information. The incremented salt load from the agricultural area was calculated to be about 1/10 of that contributed from natural sources through the interchange process. The estimated natural increment of salt represents more than one-half of the total salt load leaving the basin. Measured salinity concentrations in the surface waters near the basin outflow reach levels of approximately 5000 ppm, which is in the same range of concentrations established for the groundwater system through model verification. Figure H-16 compares computed and observed outflow functions for both water and salt for the years 1964 and 1965.

Green River above Green River, Utah, subbasin

This area is drained by the main strem of the Green River and lies immediately downstream from Ouray, Utah. Inflows consist of computed subsurface outflows and recorded surface flows from the Price River drainage and the Green River at Ouray. Contributions from inbasin tributaries are hardly significant in terms of the total flows of the Green River, but a small ungaged component was estimated by Equation 3.4 through correlation with measured flows of Minnie Maud Creek near Myton, Utah. The agricultural system had no appreciable affect on outflows as computed by the model. However, consumptive use by phreatohytes was detectable. There are no subsurface outflows, and the estimated salt load contributed from natural sources within the basin was very small. Comparisons between computed and observed outputs for this subbasin are shown by Figure H-17. Basically, inflows are virtually unmodified by the subbasin as they move to the outlet point.

San Rafael River subbasin

The San Rafael River flows eastward from the Wasatch Range and joins the Green River near the settlement of Green River, Utah. Most water and salt inflows to this subbasin are measured. The small ungaged inflow component was estimated from Equation 3.4 by correlation with precipitation. The digital computer program of Appendix G was used to estimate one or two missing months of water inflow data. Since water diversion rates to the irrigated lands were unavailable for the years modeled, the digital computer program of Appendix D was used in conjunction with previous measurements and the carrying capacities of the major canals to estimate these flows. The model indicated that, even under irrigation, deficits of water available for plant consumptive use occurred during some months of the study period. The hydrologic system was found to be sensitive to changes within the agricultural area, while the salinity flow system was less responsive. These different response characteristics are likely the result of the relatively low estimated average salinity concentration (1700 ppm) in the groundwater beneath the agricultural lands. Groundwater salinity concentrations increased in the downstream direction, and in the lower portion of the subbasin average salinity levels rise to an estimated 4300 ppm. Most of the salt load apparently originates from natural sources, and is computed in the model as a function of the total water discharge rates from the subbasin. As the surface water outflow rate increases so does the rate of salt flow which is introduced by the interchange process. This phenomenon is illustrated by Figure H-18 which presents the hydrographs and corresponding salinity output functions for the years 1964 and 1965. The total salt outflow for 1964 was approximately one-half that of 1965.

Grand Division

Colorado River above Hot Sulphur Springs, Colorado, subbasin

This subbasin drains the high western slopes of the Rocky Mountains. Precipitation is high and average temperatures are low. The predominant agricultural crop is meadow hay which grows in fields adjacent to the stream channels in the narrow valleys. The fields are flood irrigated by diverting water from the streams in unlined ditches. Because the supply of water is plentiful, there is little regulation of the irrigation diversions and the average irrigation efficiency is low (40 percent). Measured input rates of both water and salt are few, and the model verification, therefore, was somewhat gross. Ungaged water inflows were estimated by Equation 3.4. The relationship used recorded data from the Frazier River and snowmelt rates as estimated by the model. The digital computer programs of Appendices D and G were employed extensively to estimate flow records as needed. Surface outflows from the subbasin are measured in a narrow, rocky gorge, and verification studies confirmed that subsurface outflow rates are negligible. The model exhibited considerable response to changes within the agricultural component of the system, particularly the irrigation efficiency. The plant root zone is apparently well supplied with moisture because at no time were deficits indicated by the model output. It was estimated that approximately 40 percent of the total salt outflow from within the subbasin occurs from natural sources. Both the interchange process and point sources, such as saline springs, contribute to the natural salt load within the subbasin. Surface water flow rates at the outflow station were used as the basis for the interchange computations. The model verification studies suggested that large volumes of influent and effluent flow within the subbasin produce seasonal variations in the salinity concentrations of the groundwater basin. However, because no field data were available to verify this hypothesis, a constant groundwater concentration was adopted for the model. Output functions of both water and salt for the years 1964 and 1965 are shown by Figure H-19.

Eagle River subbasin

The hydrologic and salinity inputs to the Eagle River subbasin are not well monitored. Salinity records as required were estimated by the digital program of Appendix G. Ungaged input water flow rates were computed by correlation with records from Brush Creek near Gypsum, Colorado, and estimated snowmelt rates. Model results indicated that approximately 4 percent of the total outflow from the subbasin occurs beneath the gage. The estimated average irrigation efficiency for the area is very low (33 percent), and is probably attributable to the ample water supply. Model output was found to be sensitive to changes in the irrigation efficiency. Because the available soil moisture capacity of the root zone is usually filled, the model was insensitive to changes in this capacity. Salinity concentrations increase from approximately 100 ppm at inflow points to 600 ppm or more at the outflow gaging location. About two-thirds of the salt load from within the basin originates from natural sources, including the interchange phenomenon and mineral springs. Computed salt contributions from this source were relatively constant from month to month. Water discharge rates from the subbasin were used as the basis for estimating the natural salt load increment added through the interchange process. The remaining one-third of the total salt load from within the subbasin was attributed to irrigation practices. A comparison between observed and computed output is shown by Figure H-20.

Colorado River above Glenwood Springs, Colorado, subbasin

Most of the water and salinity inputs to this subbasin are measured. Even so, average ungaged water inflows average more than 400,000 acre-feet per year. The monthly distribution of these flows was estimated from Equation 3.4 by correlation with gaged flows in Surface Creek near Cedaredge, Colorado, and Troublesome Creek near Pearmont, Colorado. The digital program in Appendix G was used to estimate salinity values for some of the small unmonitored tributaries. As was anticipated from the location of the outflow gage, the model indicated no subsurface flow from the basin. Because of a relatively large acreage of irrigated land within the subbasin, both the water and salt output functions of the model were sensitive to changes within the agricultural component of the system. The salinity output function was particularly responsive to changes in the salinity concentrations of the groundwater basin beneath the irrigated lands. Except for periods of high water discharge the salt load added by natural processes was relatively constant. Much of this salt flow increment originates from thermal and saline springs along the main stream channel. Figure H-21 compares observed with computed output for the years 1964 and 1965.

Roaring Fork River subbasin

The Roaring Fork River is a major tributary to the upper Colorado River above the Gunnison and Green Rivers. Ungaged surface water inflow rates to this subbasin were estimated by correlation with average measured flow rates of West Sopris and Prince Creeks. Subsurface water inflow rates also were estimated by correlation with gaged surface flows (Equation 3.6) and by incorporating a delay of 1 month. The simulation model proved somewhat sensitive to estimated hydrologic inflow streams and to agricultural parameters. Salinity concentrations were computed as needed by the digital program in Appendix G. The model indicated that significant salt load is accumulated within the subbasin from natural sources through the interchange phenomenon. Computed salt output rates seemed particularly sensitive to groundwater salinity concentration levels. It is interesting to note that estimated average soil moisture levels rarely were less than field capacity during the study period, thus indicating that a very adequate supply of irrigation water generally is available for the valley. Observed and simulated outflows for the subbasin are compared by Figure H-22.

Colorado River above Plateau Creek subbasin

This subbasin is situated on the main channel of the Colorado River immediately upstream from Grand Valley. Only a small portion of the surface waters entering the subbasin are ungaged, and these were estimated from Equation 3.4, which utilized the measured flows of the North Fork of Fryingpan Creek near Norrie, Colorado. Even though a relatively large area of land within this basin is irrigated, changes within the agricultural system produced only small changes in the computed outflows of water and salt. This insensitivity is attributed to the large surface water inflows to the basin in comparison with the small flows within the agricultural system. According to the model, significant rates of deep percolation occur during only a month or two each year, with the soil moisture reservoir being at a generally low level for the remainder of the year. This situation reduces actual consumptive use well below the potential rate. Evapotranspiration use by phreatophytes within the basin is not significant. The salinity component of the model indicated that rates of salt flow from the agricultural system are low during years of short water supply. In some areas a favorable salt balance within the soil profile is not achieved. Approximately one-third of the total salt outflow originates from natural sources through the interchange process in the subbasin. The location of the outflow gage precludes any appreciable subsurface outflow. This observation was substantiated by the simulation model. Recorded and simulated outflows for the subbasin are compared in Figure H-23.

Plateau Creek subbasin

This subbasin lies in the high-mountainous region northwest of Grand Junction, Colorado, where melting snows are the principal source of water. The area of the subbasin is small compared with that of other subbasins included in this study. Ungaged surface water inflow rates were estimated by correlation with measured flows of Brush Creek near Colbran and Buzzard Creek near Heiberger. Groundwater inflow rates were estimated by Equation 3.6 through correlation with measured surface streams and assuming a 4-month delay. Because salinity data within the subbasin are meager, the digital computer programs in Appendices D and G were used extensively. Because the basin is relatively small, computed water discharge rates were significantly affected by changes in the parameters of the agricultural system. Diversion rates were sufficient to maintain the soil moisture content at its capacity level throughout most of the study period. The model indicated no significant subsurface outflows of water and salt from the area, and no salinity increases from natural sources through interchange processes were noted. A comparison between recorded and computed outflows of water and salt for the years 1964 and 1965 is found in Figure H-24.

Gunnison River above Gunnison, Colorado, subbasin

This subbasin is typical of the mountainous, high water-yield areas of the Rocky Mountains. Ungaged surface water inflows were estimated by Equation 3.4. The historical records used in this correlation equation were the combined flows of Ohio Creek at Baldwin, Quartz Creek near Ohio City, Tomichi Creek at Sargents, and East River near Crested Butte, all in Colorado. Salinity records are available for many of the streams within the area, but many of these data do not fall within the modeling period. The digital program in Appendix G was used to estimate missing salinity values as required. Because of ample water supplies within the subbasin, irrigation diversions generally exceed crop needs, and average irrigation efficiencies are therefore low. Model results indicated an average irrigation efficiency for the area of 30 percent. Mainly as a result of the high diversion rates, the model was sensitive to the irrigation efficiency but insensitive to the soil moisture storage capacity. Outflow from the subbasin occurs at two stations (Table D-2, Appendix D), and it is considered likely that there are some subsurface flows at each. It is estimated that about 5 percent of the total outflows of both water and salt from the area occur beneath the output gages. A large incremented salt load is added within the basin primarily through the interchange process, which was expressed in the model as a function of the surface water outflow from the subbasin. Model tests indicated a strong sensitivity to changes in the salinity concentration of the groundwater, and to salinity levels of return flow streams. Observed and computed outflows of water and salt from the basin are shown in Figure H-25.

Gunnison River above the North Fork Gunnison River subbasin

This subbasin includes the Blue Mesa Reservoir, which began filling in the latter part of October 1965. Because the study period included the months of initial reservoir filling, outflow data from the subbasins were adjusted to account for the effects of changing surface and bank storages within the reservoir. The large ungaged inflow component was estimated by Equation 3.4, using measured flows for the Uncompahgre River near Ridgeway, Colorado. Salinity concentrations for the ungaged inflow waters were estimated as a function of the measured concentrations of Soap Creek near Sapinero, Colorado. Because irrigation water supplies are ample, the average available soil moisture level rarely falls below capacity, and percolation rates to the groundwater basin are generally high. Even so, consumptive use by agricultural crops and phreatophytes within the modeled area is relatively small, and as a result the hydrologic model was insensitive to changes within the agricultural component of the system. Agricultural activities are estimated to contribute only 5 to 10 percent of the total salt outflow. The natural salt load attributable to the interchange process also comprised a small portion of the total salt outflow. The interchange process was expressed as a function of surface water outflow from the area. All water outflows from this area, including substantial exports, are recorded as surface flow. The largest single diversion is by way of the Gunnison Tunnel into the Uncompahgre River system. A comparison between observed and computed discharge functions for both water and salt is shown by Figure H-26.

Uncompahgre River subbasin

A tributary of the Gunnison River, the Uncompahgre River flows through a well developed agricultural valley. Most of the water and salt entering this subbasin are monitored at regular gaging stations. Ungaged water inflow rates were estimated from Equation 3.4, with Cow Creek near Ridgeway, Colorado, being used as the correlation station. Large imports to this subbasin occur from the Gunnison River and Cimmaron Creek drainages. Because water is readily available at a low cost, irrigation diversion rates tend to be high and evapotranspiration losses correspondingly large. The model indicated an average irrigation efficiency for the area of only 32 percent. The hydro-salinity model was sensitive to the agricultural parameters, especially irrigation efficiency, irrigation diversion rates and salinity concentrations associated with groundwater and surface water return flows. Approximately 7.0 percent of the water and salt flows from the basin occur beneath the land surface. Appreciable quantities of both surface and subsurface return flows from agriculture do not reenter the Uncompahgre River, but rather flow to the west and north sides of the Uncompahgre bench into Roubideaux Creek and thence to the Gunnison River itself. No natural salt accumulation from the interchange process was indicated by the model. Apparently, extensive cementing or seeding of the Uncompahgre River channel prevents an interchange between the stream channel and the groundwater basin. Observed and computed output graphs for both water and salt are shown by Figure H-27 for the years 1960 and 1961.

Gunnison River above Grand Junction, Colorado, subbasin

This subbasin includes both the lower portion of the Gunnison River drainage just above its confluence with the Colorado River and the drainage area of the North Fork of the Gunnison River. Water inputs to the subbasin are well monitored, with only a fraction of the total coming from ungaged sources. These flows were estimated by Equation 3.4, using a snowmelt component and measured flows of Brush Creek near Colbran, Colorado. Inflows to the subbasin also included the computed subsurface outflows from the model of the Uncompahgre River system and the surface and subsurface return flows that discharge into Roubideaux Creek and the Gunnison River. In a few cases the digital computer program in Appendix G was used to estimate missing salinity values. Changes in the agricultural parameters on the computed hydro-salinity outflow produced only slight responses in the output functions apparently because of the relatively large flows in the Gunnison River in comparison with the irrigation diversions. The model indicated that diversion rates were sufficient to keep the average soil moisture capacity of the crop root zone filled most of the time. A small subsurface water outflow from the subbasin was estimated, averaging 40,000 acre-feet per year. The model also suggested that a large portion of the salt load added within the subbasin is derived from natural sources through the interchange phenomenon, and this process was simulated as a function of the subbasin outflow. Salt contributions from the agricultural area are apparently much less than those from natural sources. Observed and computed outflows of both water and salt are compared in Figure H-28.

Colorado River above Colorado-Utah stateline subbasin

The Gunnison and Colorado Rivers join within this subbasin, and the flows of both rivers are recorded daily. Subsurface inflows to the subbasin from the Colorado and Gunnison Rivers are small, but were considered in the model development (Figure 7.2). Ungaged inflows to the subbasin were estimated from the precipitation and snowmelt components of the correlation relationships described by Equation 3.4. Water for the approximately 80,000 acres of irrigated land in this subbasin is diverted mainly from the two major rivers. Most diversions are measured and appear to be accurately recorded. Agricultural development is probably the most extensive of any area in the Upper basin, and cropland evapotranspiration uses are high. Significant abstractions also occur through consumptive use by phreatophytes. Because a large portion of the valley floor is irrigated, the hydro-salinity model output was moderately sensitive to parameter changes within the agricultural segment. Irrigation diversions apparently maintain the available soil moisture at near its capacity level most of the time. A large salt flow originates within the subbasin from both natural and agricultural sources. A small amount of that which the model indicates as natural salt loading through the interchange process actually could be salt pickup from other sources, such as industries, in the Grand Junction area. Because groundwater salinity concentrations are high, the model was sensitive to the interchange process. The model indicated that approximately 2 percent of the total water and salt outflows from the subbasin occur as subsurface movement beneath the gage. These flows amount to an average of approximately 100,000 acre-feet of water and 300,000 tons of salt per year. The agreement achieved between the computed and recorded outflow functions of both water and salt for the years 1964 and 1965 is shown by Figure H-29.

San Miguel River subbasin

The San Miguel River originates in a high mountain area with a considerable portion of the inflows to the basin contributed by melting snows. The lower reaches of the river are in an arid or semiarid region where thundershower activity and the associated pickup of salts by surface runoff are the only basin inputs. Inflow and outflow rates for both water and salt are not extensively monitored, and the digital programs in Appendices D and G were used to provide missing values. Equation 3.4 was applied in conjunction with measured flows of Beaver Creek near Norwood, Colorado, to estimate ungaged surface water inflow rates. The computed hydro-salinity outflow functions were sensitive to parameters in the agricultural system, such as diversion rates, irrigation efficiency, and groundwater salinity. The model indicated no significant subsurface outflow from the basin. Rather than the interchange process, a constant salt source, such as would occur from a salt seep or spring, was used to simulate the natural salt load. Consumptive use by phreatophytes was not significant. The model indicated that during the study period sufficient water was diverted to the irrigated lands to maintain the available soil moisture supply at the capacity level, with deep percolation to the groundwater system occurring most of the time. The agreement achieved between the observed and computed output plots is shown by Figure H-30.

Dolores River subbasin

The headwaters of the Dolores River are in the San Juan Mountain range. Because the lower portion of the subbasin is semi-arid, most of the agriculture is concentrated within the upper reaches of the drainage area. Man-made exports and imports were considered in the model development. Significant flows are exported to the Cortez, Colorado, area. Inflow rates to the modeled area of both water and salt are not well monitored. The correlation relationship described by Equation 3.4 was used to estimate ungaged surface water inflow rates, with the snowmelt component contributing the most significant fraction. Streamflow correlation was based on the measured flows of Willow Creek near Castle Gate, Utah. Irrigation diversion rates depend on water supplies available in the streams, and are thus highly variable. Generally, low soil moisture levels prevail during years of low flow, and high soil moisture levels with deep percolation to the groundwater system occur during high flow years. Model output functions were insensitive to parameter changes within the agricultural component of the system. No subsurface outflows were indicated by the model. A large volume of salt is apparently derived from natural sources within the basin, although the interchange phenomenon did not seem to apply. Rather, improved results were achieved by assuming a constant source of salt input amounting to approximately 270,000 tons per year. This rather constant salt load probably originates from salt springs, seeps, and other similar physical conditions. The general fit of the model is shown by Figure H-31 which illustrates observed and computed outflow functions for the years 1964 - 1965.

Colorado River above Cisco, Utah, subbasin

The large volume of water passing through this subbasin essentially dwarfs the effects on the computed output of the 2500 irrigated acres within the subbasin. For this reason the primary function of the model simplifies to one of routing inflows along the stream channel to the point of basin outflow. All surface inputs (both water and salt) are well measured and no correlation relationships were needed. Irrigation diversions are apparently not sufficient to maintain available soil moisture levels at field capacity for more than one or two months of each year. Probably because of the short length of the main stream channel, there are apparently no significant salt contributions from natural sources within the system. The model was sensitive to subsurface outflows, and indicated that approximately 2 percent of both water and salt leave the subbasin in this manner. Simulated and observed outflow functions for this subbasin are shown by Figure H-32.

San Juan Division

San Juan River above Arboles, Colorado, subbasin

This subbasin brings together snowmelt waters from the Continental Divide on the east and from the San Juan Mountain Range on the north. The high mean elevation precludes a well developed agricultural economy. Surface inflows of both water and salt are not well monitored, and the digital computer programs of Appendices D and G and Equation 3.4 were applied. Measured inflows for the East Fork of the San Juan River above Sand Creek near Pagosa Springs, Colorado, were used for correlation purposes in Equation 3.4. The significant snowmelt component in the relationship for this subbasin reflected the influence of the slowly melting snowpacks in the high mountains. Adequate records of diversions to the irrigated lands are available and indicate that water applications usually far exceed crop requirements. In terms of total flows within the subbasin neither the agricultural crops nor the phreatophytes consume substantial quantities of water. Further, the estimated delay time within the groundwater basin is relatively short (1.5 months) in comparison with those of other subbasins. For these reasons the model was very insensitive to the changes within the agricultural components of the system. Both inflow and outflow salinity concentrations are low ranging from 50 to 100 ppm. Most of the salt load from within the subbasin apparently originates from natural sources. This loading was estimated on the basis of the interchange phenomenon which was expressed as a function of the surface water outflow rate from the area. The model indicated no subsurface flow from the subbasin. Figure H-33 compares observed and computed outflow functions for the years 1964 and 1965.

San Juan River above Archuleta, New Mexico, subbasin

This subbasin is located in the upper part of the San Juan River basin and drains the south side of the San Juan Mountain range. The irrigated lands lie in the upper watershed areas of the two major tributaries, the Pine and Piedra Rivers. Navajo Reservoir is situated immediately upstream from the outflow ~~gaging~~ point of the subbasin. The inflows of water and salt to the modeled area are fairly well defined and include the computed subsurface inflow from the adjacent upstream subbasin. Only the snowmelt component of Equation 3.4 was required to estimate ungaged surface water inflows. As indicated by the high available soil moisture levels simulated by the model, irrigation diversions are generally adequate to meet crop consumptive use requirements. The model was only slightly sensitive to changes in agricultural parameters. The estimated salt load from agricultural sources exceeded natural source contributions through the interchange phenomenon. No subsurface outflow was indicated by the model. This result was expected because of the Navajo dam. The operation of Navajo Reservoir significantly affects the temporal distribution of basin outflows, and changes in reservoir storage were considered in the development of the model. Through an exponential relationship changes in reservoir bank storage were estimated as a function of changes in reservoir surface storage. Soil conditions at Navajo Reservoir appear to be such that only small volumes of water are contained in bank storage. Because of the difficulty in treating salt flow through a large reservoir, in modeling the salinity component of this system, the reservoir was regarded as a point of discontinuity and only measured flows of salt to and from the reservoir were considered. Figure H-34 compares observed and computed outflow functions for water and salt from the subbasin for the years 1964 and 1965.

Animas River subbasin

The Animas River is the largest tributary of the San Juan River and lies within the boundaries of both Colorado and New Mexico. Water supplies are generally sufficient to meet basin demands. Many of the hydrologic inputs are measured, but some estimates were made by the digital computer program of Appendix D and a correlation based on the snowmelt component of Equation 3.4. Salinity concentration measurements are also available for most tributaries. Canal diversions are measured and recorded for that portion of the basin contained within the State of Colorado. These records were extended to provide estimates of diversion rates to irrigated lands in New Mexico, and these values were further checked through the simulation process. Because a large portion of the total water supplies within the subbasin is used for irrigation, the computer model was sensitive to changes in the parameters of the agricultural component. The average irrigation efficiency for the area was indicated by the model to be about 60 percent. The available soil moisture storage apparently remains near capacity most of the time. Water entering the subbasin carries low salinity concentrations of 100 ppm or less, but concentration levels in the outflowing waters tend to be from three to five times higher. The increase is attributed to the concentrating effects of consumptive use to the leaching effects of irrigation return flows and to large salt contributions from natural sources. The natural salt load from the interchange process was computed as a function of the surface water outflow rate and was estimated to be approximately one-half of the total salt outflow. The model indicated that approximately 4 percent of the total outflow of water and salt from the subbasin occurs beneath the gage. Figure H-35 compares observed and computed surface outflows from the system for the years 1962 and 1963.

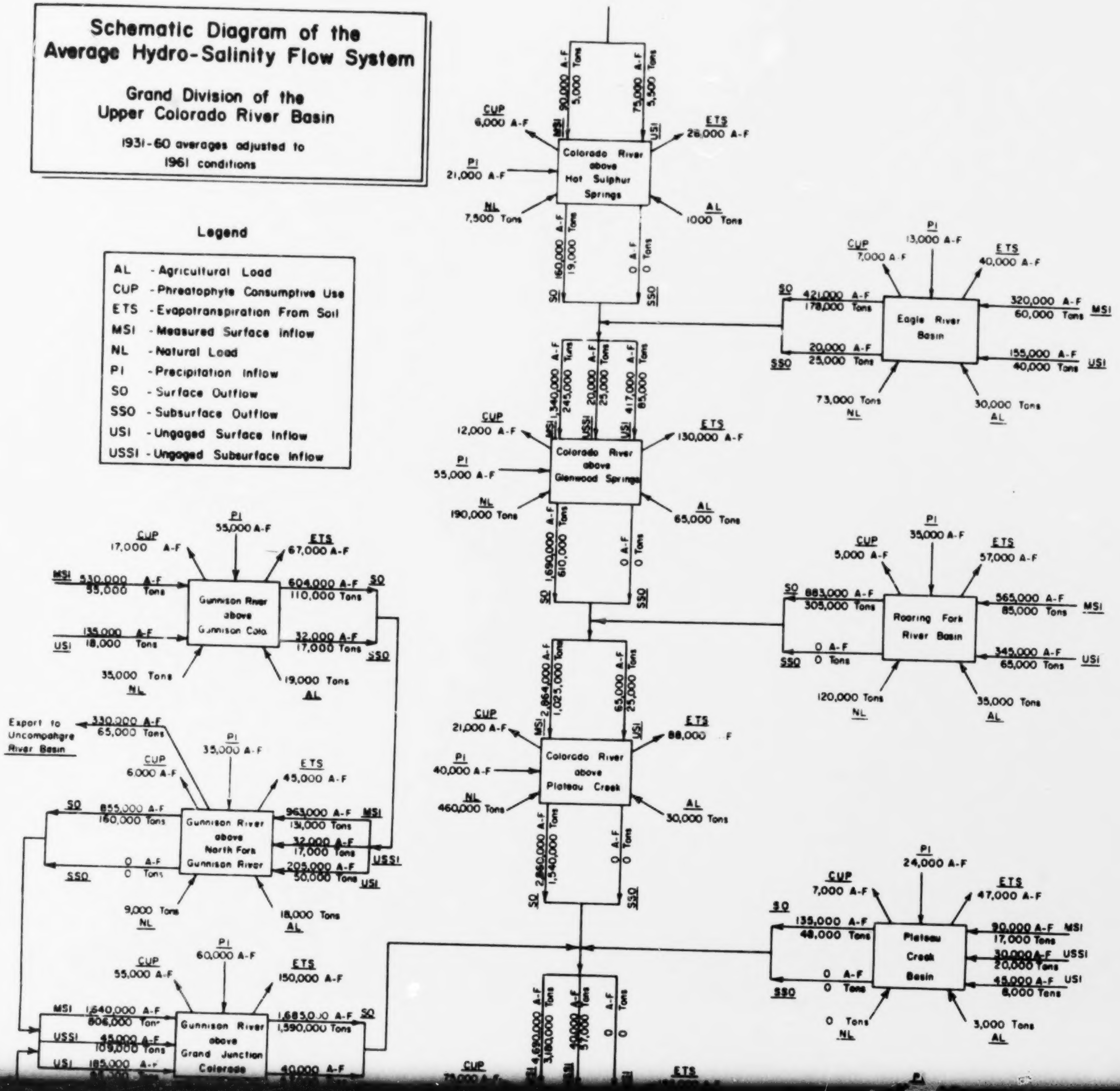
Schematic Diagram of the Average Hydro-Salinity Flow System

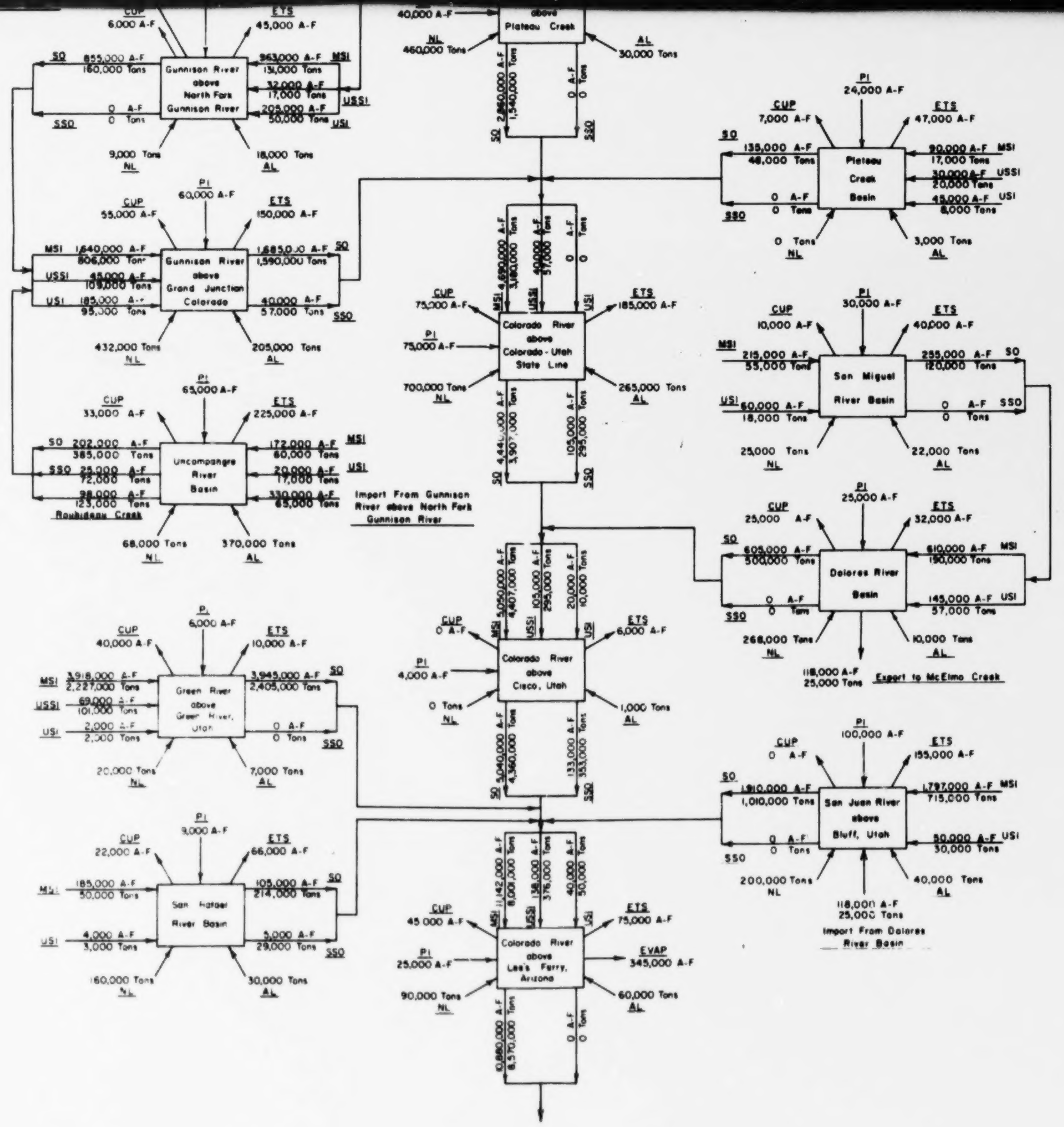
Grand Division of the Upper Colorado River Basin

1931-60 averages adjusted to
1961 conditions

Legend

AL	- Agricultural Load
CUP	- Phreatophyte Consumptive Use
ETS	- Evapotranspiration From Soil
MSI	- Measured Surface Inflow
NL	- Natural Load
PI	- Precipitation Inflow
SO	- Surface Outflow
SSO	- Subsurface Outflow
USI	- Ungaged Surface Inflow
USSI	- Ungaged Subsurface Inflow


Colorado River above Hot Sulphur Springs
MSI 90,000 A-F 5,000 Tons
USI 75,000 A-F 5,500 Tons
CUP 6,000 A-F
PI 21,000 A-F
NL 7,500 Tons
ETS 28,000 A-F
AL 1000 Tons
SO 160,000 A-F 19,000 Tons
SSO 0 A-F 0 Tons
Eagle River Basin
CUP 7,000 A-F
PI 13,000 A-F
ETS 40,000 A-F
MSI 320,000 A-F 60,000 Tons
USI 155,000 A-F 40,000 Tons
SO 421,000 A-F 178,000 Tons
SSO 20,000 A-F 25,000 Tons
NL 73,000 Tons
AL 30,000 Tons
Colorado River above Glenwood Springs
MSI 1,340,000 A-F 245,000 Tons
USSI 20,000 A-F 25,000 Tons
USI 417,000 A-F 85,000 Tons
CUP 12,000 A-F
PI 55,000 A-F
NL 190,000 Tons
ETS 130,000 A-F
AL 65,000 Tons
SO 1,690,000 A-F 610,000 Tons
SSO 0 A-F 0 Tons
Roaring Fork River Basin
CUP 5,000 A-F
PI 35,000 A-F
ETS 57,000 A-F
MSI 565,000 A-F 85,000 Tons
USI 345,000 A-F 65,000 Tons
SO 883,000 A-F 305,000 Tons
SSO 0 A-F 0 Tons
NL 120,000 Tons
AL 35,000 Tons
Colorado River above Plateau Creek
MSI 2,864,000 A-F 1,025,000 Tons
USI 65,000 A-F 25,000 Tons
CUP 21,000 A-F
PI 40,000 A-F
NL 460,000 Tons
ETS 88,000 F
AL 30,000 Tons
SO 2,860,000 A-F 1,540,000 Tons
SSO 0 A-F 0 Tons
Plateau Creek Basin
CUP 7,000 A-F
PI 24,000 A-F
ETS 47,000 A-F
MSI 90,000 A-F 17,000 Tons
USSI 30,000 A-F 20,000 Tons
USI 45,000 A-F 6,000 Tons
SO 135,000 A-F 48,000 Tons
SSO 0 A-F 0 Tons
NL 0 Tons
AL 3,000 Tons
4,690,000 A-F 3,180,000 Tons
90,000 A-F 57,000 Tons
0 A-F 0 Tons
CUP 75,000 A-F
ETS
PI
Gunnison River above Gunnison Colo.
CUP 17,000 A-F
PI 55,000 A-F
ETS 67,000 A-F
MSI 530,000 A-F 55,000 Tons
USI 135,000 A-F 18,000 Tons
SO 604,000 A-F 110,000 Tons
SSO 32,000 A-F 17,000 Tons
NL 35,000 Tons
AL 19,000 Tons
Export to Uncompahgre River Basin
330,000 A-F 65,000 Tons
Gunnison River above North Fork Gunnison River
CUP 6,000 A-F
PI 35,000 A-F
ETS 45,000 A-F
MSI 963,000 A-F 131,000 Tons
USSI 32,000 A-F 17,000 Tons
USI 205,000 A-F 50,000 Tons
SO 855,000 A-F 160,000 Tons
SSO 0 A-F 0 Tons
NL 9,000 Tons
AL 18,000 Tons
Gunnison River above Grand Junction Colorado
CUP 55,000 A-F
PI 60,000 A-F
ETS 150,000 A-F
MSI 1,640,000 A-F 806,000 Tons
USSI 45,000 A-F 109,000 Tons
USI 185,000 A-F
SO 1,685,000 A-F 1,590,000 Tons
40,000 A-F


Gunnison River above North Fork Gunnison River
CUP 6,000 A-F
ETS 45,000 A-F
SO 855,000 A-F 160,000 Tons
SSO 0 A-F 0 Tons
MSI 963,000 A-F 131,000 Tons
USSI 32,000 A-F 17,000 Tons
USI 205,000 A-F 50,000 Tons
NL 9,000 Tons
AL 18,000 Tons
Gunnison River above Grand Junction Colorado
PI 60,000 A-F
CUP 55,000 A-F
ETS 150,000 A-F
MSI 1,640,000 A-F 806,000 Tons
USSI 45,000 A-F 109,000 Tons
USI 185,000 A-F 95,000 Tons
SO 1,685,000 A-F 1,590,000 Tons
SSO 40,000 A-F 57,000 Tons
NL 432,000 Tons
AL 205,000 Tons
Uncompahgre River Basin
PI 65,000 A-F
CUP 33,000 A-F
ETS 225,000 A-F
SO 202,000 A-F 385,000 Tons
SSO 25,000 A-F 72,000 Tons
98,000 A-F 123,000 Tons Roubideau Creek
MSI 172,000 A-F 60,000 Tons
USI 20,000 A-F 17,000 Tons
330,000 A-F 65,000 Tons
Import From Gunnison River above North Fork Gunnison River
NL 68,000 Tons
AL 370,000 Tons
Colorado River above Plateau Creek
40,000 A-F
NL 460,000 Tons
AL 30,000 Tons
SO 2,860,000 A-F 1,540,000 Tons
SSO 0 A-F 0 Tons
Plateau Creek Basin
PI 24,000 A-F
CUP 7,000 A-F
ETS 47,000 A-F
SO 135,000 A-F 48,000 Tons
SSO 0 A-F 0 Tons
MSI 90,000 A-F 17,000 Tons
USSI 30,000 A-F 20,000 Tons
USI 45,000 A-F 8,000 Tons
NL 0 Tons
AL 3,000 Tons
Colorado River above Colorado - Utah State Line
MSI 4,690,000 A-F 3,180,000 Tons
USSI 40,000 A-F 57,000 Tons
USI 0 A-F 0 Tons
CUP 75,000 A-F
PI 75,000 A-F
ETS 185,000 A-F
NL 700,000 Tons
AL 265,000 Tons
SO 4,440,000 A-F 3,907,000 Tons
SSO 105,000 A-F 295,000 Tons
San Miguel River Basin
PI 30,000 A-F
CUP 10,000 A-F
ETS 40,000 A-F
MSI 215,000 A-F 55,000 Tons
USI 60,000 A-F 18,000 Tons
SO 255,000 A-F 120,000 Tons
SSO 0 A-F 0 Tons
NL 25,000 Tons
AL 22,000 Tons
Dolores River Basin
PI 25,000 A-F
CUP 25,000 A-F
ETS 32,000 A-F
SO 605,000 A-F 500,000 Tons
SSO 0 A-F 0 Tons
MSI 610,000 A-F 190,000 Tons
USI 145,000 A-F 57,000 Tons
NL 268,000 Tons
AL 10,000 Tons
118,000 A-F 25,000 Tons Export to McElmo Creek
Colorado River above Cisco, Utah
MSI 5,050,000 A-F 4,407,000 Tons
USSI 105,000 A-F 295,000 Tons
USI 20,000 A-F 10,000 Tons
CUP 0 A-F
PI 4,000 A-F
ETS 6,000 A-F
NL 0 Tons
AL 1,000 Tons
SO 5,040,000 A-F 4,360,000 Tons
SSO 133,000 A-F 353,000 Tons
Green River above Green River, Utah
PI 6,000 A-F
CUP 40,000 A-F
ETS 10,000 A-F
MSI 3,918,000 A-F 2,227,000 Tons
USSI 69,000 A-F 101,000 Tons
USI 2,000 A-F 2,000 Tons
SO 3,945,000 A-F 2,405,000 Tons
SSO 0 A-F 0 Tons
NL 20,000 Tons
AL 7,000 Tons
San Rafael River Basin
PI 9,000 A-F
CUP 22,000 A-F
ETS 66,000 A-F
MSI 185,000 A-F 50,000 Tons
USI 4,000 A-F 3,000 Tons
SO 105,000 A-F 214,000 Tons
SSO 5,000 A-F 29,000 Tons
NL 160,000 Tons
AL 30,000 Tons
San Juan River above Bluff, Utah
PI 100,000 A-F
CUP 0 A-F
ETS 155,000 A-F
SO 1,910,000 A-F 1,010,000 Tons
SSO 0 A-F 0 Tons
MSI 1,797,000 A-F 715,000 Tons
USI 50,000 A-F 30,000 Tons
NL 200,000 Tons
AL 40,000 Tons
118,000 A-F 25,000 Tons Import From Dolores River Basin
Colorado River above Lee's Ferry, Arizona
MSI 11,142,000 A-F 8,001,000 Tons
USSI 138,000 A-F 376,000 Tons
USI 40,000 A-F 50,000 Tons
CUP 45,000 A-F
PI 25,000 A-F
ETS 75,000 A-F
EVAP 345,000 A-F
NL 90,000 Tons
AL 60,000 Tons
10,880,000 A-F 8,570,000 Tons
0 A-F 0 Tons

90 - 90A

Figure 7.2. Schematic diagram of the average hydro-salinity flow system, Grand River division.

San Juan River above Farmington, New Mexico, subbasin

This subbasin is immediately downstream from Navajo Reservoir and forms a part of the study area considered in a proposed irrigation project which is discussed in detail by the following chapter. The Animas River joins the San Juan River within this subbasin, and these two streams comprise the major inflow. The computed subsurface outflows from the Animas River subbasin also were included as inflows to the system. Ungaged surface water inflows to the basin were estimated by Equation 3.4, using only the precipitation component. Heavy thunderstorm activity in the subbasin made ungaged inflows difficult to model, especially with reference to the salinity concentrations which appeared to vary with storm location. A constant salinity level of 1000 ppm was somewhat arbitrarily assigned to these flows. Irrigation diversion records are sparse, and diversions were therefore estimated on an acre-foot per acre per year basis. According to the model results, available soil moisture levels are usually near capacity. The irrigated area is small and depletions by phreatophytes and agricultural crops is not significant in terms of total water flows within the subbasin. Salt load increases from all sources are minor, perhaps because the groundwater movement is interrupted by the Navajo Dam and the length of river channel within the basin is short. Estimates of salt load increases from natural sources were based on the interchange concept utilizing surface water outflows. Slightly more than 1 percent of the total basin outflow occurs as subsurface movement. Figure H-36 compares the observed and computed outflow time graphs for the years 1964 and 1965.

LaPlata River subbasin

The LaPlata River is a direct tributary to the San Juan River and lies within the states of Colorado and New Mexico. This drainage area is subject to extremely acute water shortages, especially during the late summer months. The hydrologic inputs to the subbasin are adequately monitored, but water salinity concentration measurements are minimal. Digital computer programs in both Appendices D and G were used to provide salinity estimates as needed. The small ungaged surface water inflow component was estimated from Equation 3.4 using correlations with precipitation and snowmelt. Canal diversion records were available for the portion of the basin within Colorado, and these records were used as a basis for estimating the diversion rates for irrigated lands in New Mexico, and these values were further checked through the simulation process. Because of the generally short supply of irrigation water, parameter changes in the agricultural component of the model significantly altered computed outflows from the basin. Actual plant consumptive use rates are frequently less than potential rates during summer months when available soil moisture supplies become critical. At times some deposition of salt in the soil profile of the agriculture lands was indicated by the model. It was estimated from the model results that approximately two-thirds of the total salt outflow from the basin originates from natural sources. Salinity levels are further increased by the concentrating effects of evapotranspiration so that concentrations in the outflowing waters tend to be high. However, because water outflow rates are low, the total annual outflow of salt from the subbasin is comparatively small (Figure H-37). Because only one concentration measurement per month was available at the outflow point, good agreement between the observed and computed salt outflow functions was not achieved. A small amount of subsurface outflow beneath the gage was indicated by the model.

San Juan River above Shiprock, New Mexico, subbasin

This subbasin and the one immediately upstream (above Farmington, New Mexico) form the study area considered in a proposed irrigation project which is discussed in the following chapter. The inflows to the subbasin are composed primarily of discharge from the adjacent upstream area. The irregular occurrence of thundershower activity in the Chaco basin, a tributary to the San Juan River, required a precipitation correlation, using Equation 3.4 to estimate ungaged surface water inflows. Precipitation data for this correlation were recorded at the Chaco Natural Monument station. A salinity concentration of 1200 ppm was adopted for the ungaged water inflow component. Irrigation diversions were estimated on an acre-foot per acre per year basis. The model indicated that these diversions maintained available soil moisture supplies within the irrigated lands at near capacity level most of the time. The agricultural area is small and water depletions by agricultural crops and phreatophytes are insignificant. Salt contributions within the subbasin from either agricultural or natural sources are small and appear to be nearly constant. Contributions from natural sources were estimated on the basis of the interchange process as a function of surface water outflow from the basin. The model was insensitive to changes in any agricultural parameter. An irrigation canal, called the Farmer's Ditch, bypasses the outflow gage, but flow rates in the canal are measured, and these records were included in the total outflow figures for the subbasin. The model indicated no subsurface flow from the subbasin. Observed and computed outflows from the basin for the years 1964 and 1965 are compared by Figure H-38.

San Juan River above Bluff, Utah, subbasin

This subbasin involves an extremely large land area, most of which is desert. The whole area is subject to substantial thundershower activity, but inputs and outputs are well defined by measured data. The small volume of ungaged inflow that occurs was estimated by correlation procedures from Equation 3.4 using the snowmelt and precipitation components. No phreatophyte acreage was incorporated in the model although small areas of this vegetation probably occur. Most of the agricultural development in the subbasin is situated in the area of Cortez, Colorado, but small irrigated areas exist on many of the perennial tributaries. Additional water is imported to the Cortez area from the Dolores River system, and these flows were included as inputs to the model. A fairly long time increment is required for the deep percolating agricultural flows to be reflected in the outflow hydrograph. Major changes in the parameters of the agricultural component of the model produced observable effects on computed outflows. In terms of total irrigation diversions consumptive use depletions are large, and return flows from the Cortez area are, therefore, highly saline. On an average annual basis the in-basin salt load increments resulting from the agricultural system and natural sources were estimated at approximately 40,000 tons and 200,000 tons, respectively. It is likely that some ungaged inflows of salt from non-perennial streams were incorporated into the contribution assigned to natural sources from the interchange process. This contribution was estimated as a function of the total surface water outflow from the basin. The model indicated no subsurface flow from the area. Observed and simulated outflow functions for water and salt corresponding to the years 1964 and 1965 are shown by Figure H-39.

Colorado River above Lee Ferry, Arizona, subbasin

This subbasin represents the termination point for the entire Upper Colorado River basin. The Green, Colorado, and San Juan Rivers all flow into this subbasin. Lake Powell lies within its boundaries. A change at any point within the entire Upper basin is reflected in the outflow of this subbasin at Lee Ferry. Geographically, the area is very large (Appendix A). Initially an attempt was made to develop hydro- salinity models for several parts of this subbasin. For example, hydrologic models were considered for the Escalante and Dirty Devil River systems. However, hydrologic and salinity data for these systems are very sparse. On the Dirty Devil River, for example, several reservoirs in the upper reaches produce considerable flow regulation, but no data are available on reservoir releases. In addition, salinity data within these two river systems are limited to one or two outflow values. Hence, these subdivisions as originally outlined were deleted from the model. A hydrologic model also was considered for the Colorado River at Hite, Utah, immediately below the confluence of the Green and Colorado Rivers. However, flow measurements at this station were discontinued prior to 1960. Rather than to develop a simulation model based entirely on correlated flows, this proposed subdivision was deleted from the model of the Upper basin system. The measured surface flows of the Green, Colorado, and San Juan Rivers comprise most of the inflow to this subbasin. However, the computed subsurface outflows of the San Rafael River basin and the Colorado River above Cisco, Utah, also were included in the estimated total inflow to this subbasin. The small ungaged surface inflow component was estimated by Equation 3.4 using only the precipitation contribution. Agricultural lands in this subbasin are located on the perennial tributary streams, including the Dirty Devil and Escalante Rivers. Irrigation diversions are small in comparison with total basin inflows and outflows, and, therefore, influence the hydrologic and salinity flow systems only slightly. The primary factor affecting the hydrologic system is evaporation from Lake Powell. The model indicated that no subsurface flow from the subbasin occurs. This result was anticipated because of the barrier created by Glen Canyon Dam. Lake Powell was simulated hydrologically, but as with all major reservoirs in this study the lake was treated as a point of discontinuity in the formulation of the salinity model. In the hydrologic model of the reservoir, changes in both surface and bank storages were considered. Through an exponential relationship bank storage changes were estimated as a function of changes in reservoir surface storage. The model was tested with data recorded during the initial filling of the reservoir, and the results indicated rather large inflow volumes to bank storage. Figure H-40 compares observed and computed outflow functions from the subbasin for the years 1964 and 1965.

A Summary of Results from the Subbasin Hydro-Salinity Models

Figures H-1 through H-40 are based on the same criteria as Figure 6.11 and constitute a comparison between observed and computed water and salt outflow time functions for each subbasin. For each figure a measure of the agreement achieved is indicated by the correlation coefficient, R^2. Mean monthly outflow figures over a period of two years (24 points) were used in this analysis.

On the basis of information from the model of each subbasin and experience gained throughout this study average annual flow estimates were prepared for both the hydrologic and salinity systems within the Upper Colorado River basin. On the basis of these estimates schematic flow diagrams for the Green, Grand, and San Juan divisions were prepared and these are shown by Figures 7.1, 7.2, and 7.3, respectively. The estimates of evapotranspiration losses through crops and phreatophytes are considered to be reasonably close to long term average annual values. A similar degree of confidence is expressed in the long term estimates associated with measured inflows (short term) and computed subsurface outflows of water and salt, and the incremental salt loads contributed from the agricultural system. In most cases it was possible to compute on the basis of available data long term average values for the surface outflows of water and salt. Additions to the salinity flow system from natural sources within the modeled areas were attributed primarily to the interchange phenomenon as expressed by Equation 4.15. Ungaged inflows of water and salt to the modeled areas were estimated by correlation procedures. These estimates could, of course,

Figure 7.3. Schematic diagram of the average hydro-salinity flow system, San Juan division.

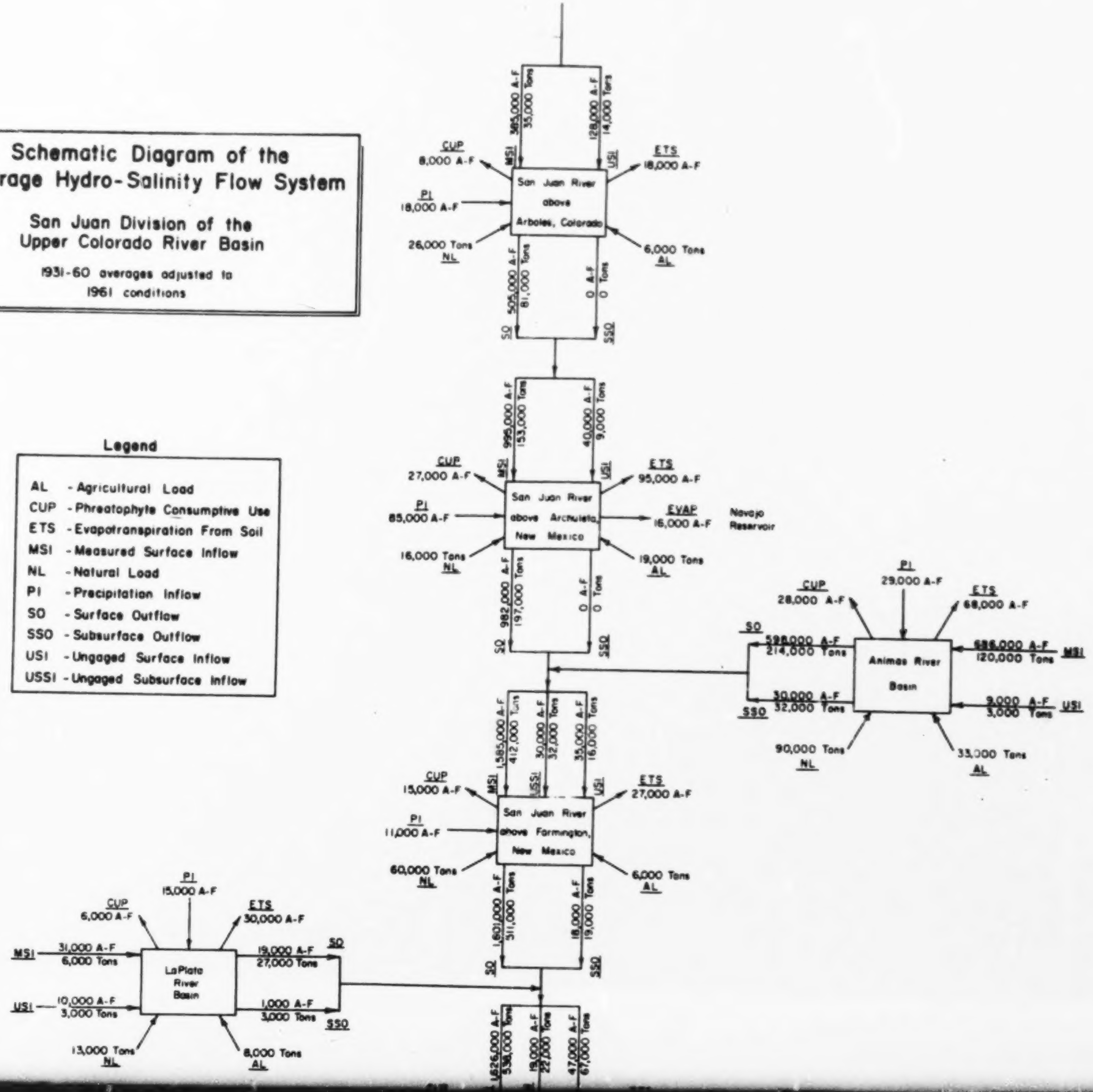
Schematic Diagram of the Average Hydro-Salinity Flow System

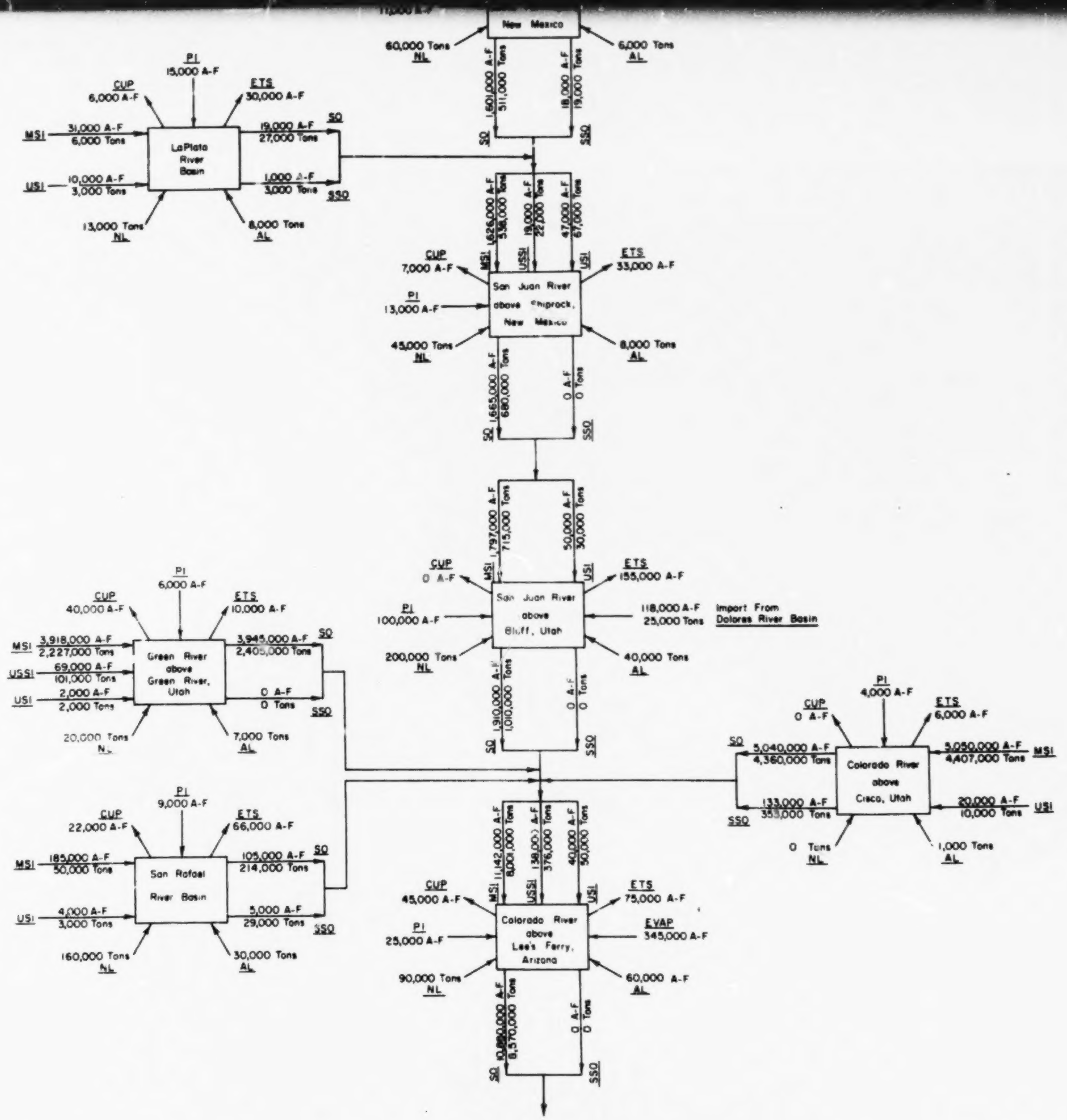
San Juan Division of the
Upper Colorado River Basin

1931-60 averages adjusted to
1961 conditions

Legend

AL - Agricultural Load
CUP - Phreatophyte Consumptive Use
ETS - Evapotranspiration From Soil
MSI - Measured Surface Inflow
NL - Natural Load
PI - Precipitation Inflow
SO - Surface Outflow
SSO - Subsurface Outflow
USI - Ungaged Surface Inflow
USSI - Ungaged Subsurface Inflow


San Juan River above Arboles, Colorado
MSI 385,000 A-F 35,000 Tons
USI 128,000 A-F 14,000 Tons
CUP 8,000 A-F
ETS 18,000 A-F
PI 18,000 A-F
26,000 Tons NL
6,000 Tons AL
SO 505,000 A-F 81,000 Tons
SSO 0 A-F 0 Tons
San Juan River above Archuleta, New Mexico
MSI 995,000 A-F 153,000 Tons
USI 40,000 A-F 9,000 Tons
CUP 27,000 A-F
ETS 95,000 A-F
PI 85,000 A-F
EVAP 16,000 A-F
Navajo Reservoir
16,000 Tons NL
19,000 Tons AL
SO 982,000 A-F 197,000 Tons
SSO 0 A-F 0 Tons
Animas River Basin
CUP 28,000 A-F
PI 29,000 A-F
ETS 68,000 A-F
MSI 686,000 A-F 120,000 Tons
USI 9,000 A-F 3,000 Tons
SO 598,000 A-F 214,000 Tons
SSO 30,000 A-F 32,000 Tons
90,000 Tons NL
33,000 Tons AL
San Juan River above Farmington, New Mexico
MSI 1,585,000 A-F 412,000 Tons
USSI 30,000 A-F 32,000 Tons
USI 35,000 A-F 16,000 Tons
CUP 15,000 A-F
ETS 27,000 A-F
PI 11,000 A-F
60,000 Tons NL
6,000 Tons AL
SO 1,601,000 A-F 311,000 Tons
SSO 18,000 A-F 19,000 Tons
LaPlata River Basin
CUP 6,000 A-F
PI 15,000 A-F
ETS 30,000 A-F
MSI 31,000 A-F 6,000 Tons
USI 10,000 A-F 3,000 Tons
SO 19,000 A-F 27,000 Tons
SSO 1,000 A-F 3,000 Tons
13,000 Tons NL
8,000 Tons AL
1,626,000 A-F 538,000 Tons
19,000 A-F 22,000 Tons
47,000 A-F 67,000 Tons


11,000 A-F
New Mexico
60,000 Tons
NL
6,000 Tons
AL
1,601,000 A-F
511,000 Tons
18,000 A-F
19,000 Tons
SO
SSO
LaPlata River Basin
PI
15,000 A-F
CUP
6,000 A-F
ETS
30,000 A-F
MSI
31,000 A-F
6,000 Tons
USI
10,000 A-F
3,000 Tons
19,000 A-F
27,000 Tons
SO
1,000 A-F
3,000 Tons
SSO
13,000 Tons
NL
8,000 Tons
AL
San Juan River above Shiprock, New Mexico
MSI
1,626,000 A-F
538,000 Tons
USSI
19,000 A-F
22,000 Tons
USI
47,000 A-F
67,000 Tons
CUP
7,000 A-F
ETS
33,000 A-F
PI
13,000 A-F
45,000 Tons
NL
8,000 Tons
AL
1,665,000 A-F
680,000 Tons
SO
0 A-F
0 Tons
SSO
San Juan River above Bluff, Utah
MSI
1,797,000 A-F
715,000 Tons
USI
50,000 A-F
30,000 Tons
CUP
0 A-F
ETS
155,000 A-F
PI
100,000 A-F
118,000 A-F
25,000 Tons
Import From Dolores River Basin
200,000 Tons
NL
40,000 Tons
AL
1,910,000 A-F
1,010,000 Tons
SO
0 A-F
0 Tons
SSO
Green River above Green River, Utah
PI
6,000 A-F
CUP
40,000 A-F
ETS
10,000 A-F
MSI
3,918,000 A-F
2,227,000 Tons
USSI
69,000 A-F
101,000 Tons
USI
2,000 A-F
2,000 Tons
3,945,000 A-F
2,405,000 Tons
SO
0 A-F
0 Tons
SSO
20,000 Tons
NL
7,000 Tons
AL
San Rafael River Basin
PI
9,000 A-F
CUP
22,000 A-F
ETS
66,000 A-F
MSI
185,000 A-F
50,000 Tons
USI
4,000 A-F
3,000 Tons
105,000 A-F
214,000 Tons
SO
5,000 A-F
29,000 Tons
SSO
160,000 Tons
NL
30,000 Tons
AL
Colorado River above Cisco, Utah
PI
4,000 A-F
CUP
0 A-F
ETS
6,000 A-F
SO
5,040,000 A-F
4,360,000 Tons
5,050,000 A-F
4,407,000 Tons
MSI
133,000 A-F
353,000 Tons
SSO
20,000 A-F
10,000 Tons
USI
0 Tons
NL
1,000 Tons
AL
Colorado River above Lee's Ferry, Arizona
MSI
11,142,000 A-F
8,001,000 Tons
USSI
138,000 A-F
376,000 Tons
USI
40,000 A-F
50,000 Tons
CUP
45,000 A-F
ETS
75,000 A-F
PI
25,000 A-F
EVAP
345,000 A-F
90,000 Tons
NL
60,000 A-F
AL
10,880,000 A-F
8,570,000 Tons
SO
0 A-F
0 Tons
SSO

BLANK PAGE

be improved by the acquisition of additional data. Additional information concerning the development of the flow diagrams of Figures 7.1, 7.2, and 7.3 is contained in Chapter VI under the discussion on Figure 6.15 for the White River subbasin.

The 1931-60 average annual water discharge rate from the Upper basin, modified to 1960 conditions, is estimated to be 10,880,000 acre-feet (Figure 7.3). Corresponding average annual flows for the Green River, the Colorado River above Cisco, Utah, and the San Juan River are 4,055,000, 5,173,000, and 1,910,000 acre-feet, respectively. The average annual virgin flow at Lee Ferry consists of about 10,500,000 acre-feet of water which is measured directly at points on tributaries to the main stem rivers, and approximately 3,200,000 acre-feet of ungaged tributary flows and precipitation which falls directly on the water surfaces of main stem reservoirs. Of the ungaged inflows more than one-half (1,800,000 acre-feet) originates within the Grand division (Colorado). These figures lead to the conclusion that the hydrologic system within the Upper basin can be reasonably well defined.

The 1931-60 average annual salt discharge from the Upper basin at Lee Ferry is estimated to be 8,570,000 tons (Figure 7.3). Of this total, approximately 2,650,000 tons, 4,710,000 tons, and 1,010,000 tons are contributed by the Green River system, the Colorado River above Cisco, Utah, and the San Juan River system, respectively. This total salt discharge produces an average salinity concentration at Lee Ferry of 579 ppm. Corresponding salinity levels in the surface waters of the Green, Colorado, and San Juan divisions at their points of discharge are, respectively, 475, 640, and 390 ppm.

On an average annual basis an estimated 2,650,000 acre-feet of water is consumed by agricultural crops within the Upper Colorado River basin (Figures 7.1, 7.2, and 7.3). Based on the estimated irrigated area of 1,410,000 acres in the entire Upper basin (Appendix F), this evapotranspiration rate is equivalent to 1.88 acre-feet per acre per year. Average total diversions for irrigation are approximately 6,740,000 acre-feet (Appendix E) for an average annual diversion rate of 4.8 acre-feet per acre.

The average annual depletion of water attributable to the activities of man in the Upper basin include evapotranspiration losses at 2,650,000 acre-feet and main stem reservoir evaporation losses of 440,000 acre-feet. If these depletion losses were eliminated, the estimated 1931-60 average annual virgin or natural flow of the Colorado at Lee Ferry would be approximately 14 million acre-feet. Consumptive use by phreatophytes accounts for an estimated additional average loss of approximately 910,000 acre-feet per year. This depletion is based on an estimated phreatophyte area of 245,000 acres (Appendix F) within the Upper basin, and is, therefore, equivalent to an average annual consumptive use rate of about 3.7 acre-feet per acre.

Each consumptive depletion tends to produce a concentration of a particular salt load within the hydrologic system. For example, within the Upper basin it is estimated that average salinity concentrations at Lee Ferry are increased by 22, 45, and 113 ppm by reservoir evaporation, consumptive use by phreatophytes, and agricultural evapotranspiration, respectively. Elimination of the first two losses, though not feasible at the present time, would reduce the average salinity level at Lee Ferry to 512 ppm. The increase in salinity concentration at Lee Ferry due to cropland evapotranspiration is almost identical in both the Green and Grand divisions and is equal to approximately 50 ppm.

Salinity measurements of tributary streams within the various subbasins of the Upper basin account for approximately 1,700,000 tons of salt in comparison with the average annual outflow of 8,570,000 tons recorded at Lee Ferry. On the basis of these figures only 20 percent of the 1931-60 average annual salt flow from the Upper basin is measured with respect to its area of origin. This limitation of available salinity information explains in part the difficulty encountered in simulating the salt flow system. The simulation models indicated that the remainder of the total average annual salt load originates from the following sources: (1) 1,070,000 tons from ungaged tributary inflows; (2) 1,530,000 tons from pick-up of salt by irrigation return flows; and (3) 4,260,000 tons from natural diffused and point sources within the system. It is recognized that differences of opinion exist as to the relative magnitudes of salt contributions from the above sources. Additional work, as suggested by Chapter IX, is needed to further define the salinity flow system.

Assuming that the dissolved solids originate as indicated, the salt load from natural sources produces an average salinity concentration of 288 ppm in the waters of the Colorado River at Lee Ferry. Comparable figures for the Green River system, the Colorado River at Cisco, Utah, and the San Juan River system are 250, 340, and 170 ppm, respectively. These concentrations correspond to average total annual salt contributions from natural sources within the Green, Grand, and San Juan divisions of 1,370,000, 2,350,000 and 540,000 tons, respectively. Average annual salt flows from each division attributable to the agricultural system are 305,000, 1,050,000, 175,000 tons, respectively.

These figures indicate that the activities of man are responsible for an average increase in total dissolved solids of 239 ppm within the Upper basin. An increase of 113 ppm results from the concentrating effects of crop evapotranspiration; the incremental salt load associated with return flows from the irrigated lands produces an increase of 104 ppm; and the concentrating effects of reservoir evaporation are responsible for an increase of 22 ppm. If these salinity increases attributable to man were eliminated, it is estimated that the average concentration of total dissolved solids within the outflow waters of the Upper Colorado River basin would be reduced to approximately 340 ppm under 1931-60 conditions of flow.

CHAPTER VIII
SIMULATION AS A MANAGEMENT TOOL

Sound water resource management requires thorough and thoughtful planning in harmony with overall public goals and needs. Water is an important key to successful development, and effective planning must consider the various consequences of water resource manipulation. This objective can be adequately met only by rapid and accurate quantitative assessment of various possible management alternatives. The utility of computer models of entire water resource systems as a management tool is thus suggested. In this chapter the application of computer simulation techniques to a management study within two of the subbasins of the Upper Colorado River drainage is demonstrated.

Management Alternatives

Since the water resources within the Upper Colorado River basin are now nearing full utilization, the application of sound management principles based upon a consideration of various alternatives is becoming increasingly important. Many management alternatives involving both water quantity and water quality might be considered, and only a few will be cited for illustrative purposes. With reference to water quantity, management alternatives might include the development of new sources of water by such means as importation from other basins and weather modification. Consideration might also be given to techniques which extend available in-basin supplies, such as those which reduce evapotranspiration losses (suppressing evaporation reducing phreatophyte acreage, diverting water to other uses). Water quality considerations might include ways of controlling salinity contributions from both natural sources and those which directly result from the activities of man. In the Upper Colorado River basin, however, more research is needed to delineate between natural and man induced salt loading before stringent, and perhaps unnecessary, control are placed on human activities.

One example of a recently initiated salinity control measure involves the plugging of two flowing wells in the White River basin by the Federal Water Pollution Control Administration (1969). These two wells, plugged with a cement slurry, were estimated to reduce the salt load of the White River by 62,500 tons annually, or about 19 percent of the average annual salinity load of the White River near Watson, Utah.

All water management alternatives need to be considered in terms of existing legal, political, and institutional constraints, and should be evaluated through a particular set of social objectives, economic and otherwise. This study has involved only the hydrologic and salinity aspects of the system. Other dimensions could be added to the model. In its present state, however, the model is adequate to demonstrate the utility of computer simulation for quickly examining many of the consequences of a wide range of water resource management alternatives.

Evaluation of a Proposed Irrigation Project

To demonstrate the utility of the computer simulation model for planning and management purposes, the hydro-salinity model developed in the preceding chapters will be used to examine a proposed development project.

Proposed development project

A current reevaluation of a proposed irrigation development (Bureau of Reclamation, 1966) would utilize the recently constructed Navajo Dam and Reservoir for the regulation and storage of the waters of the San Juan River to irrigate an additional 110,600 acres of irrigable land. The project authorizing act in June of 1962 allowed for the diversion of over 500,000 acre-feet of water to the proposed irrigated area.

Most of the project lands begin at Bloomfield, New Mexico, and extend west to the Chaco River system, and are located south of the San Juan River. About one-third of the project lands are contained within the Navajo Indian reservation in the north western portion of New Mexico. Figure 8.1 illustrates in a general manner the location of the project and the proposed lands of the irrigation development.

The basic plan would divert water into a main highline canal, heading at the left abutment of Navajo Dam, and convey the water to the west some 29 miles to a pumping plant. At this point the water would be divided into two portions with one part being lifted by direct turbine pumps into two canals, and the other part continuing westward in another gravity canal. Approxi-

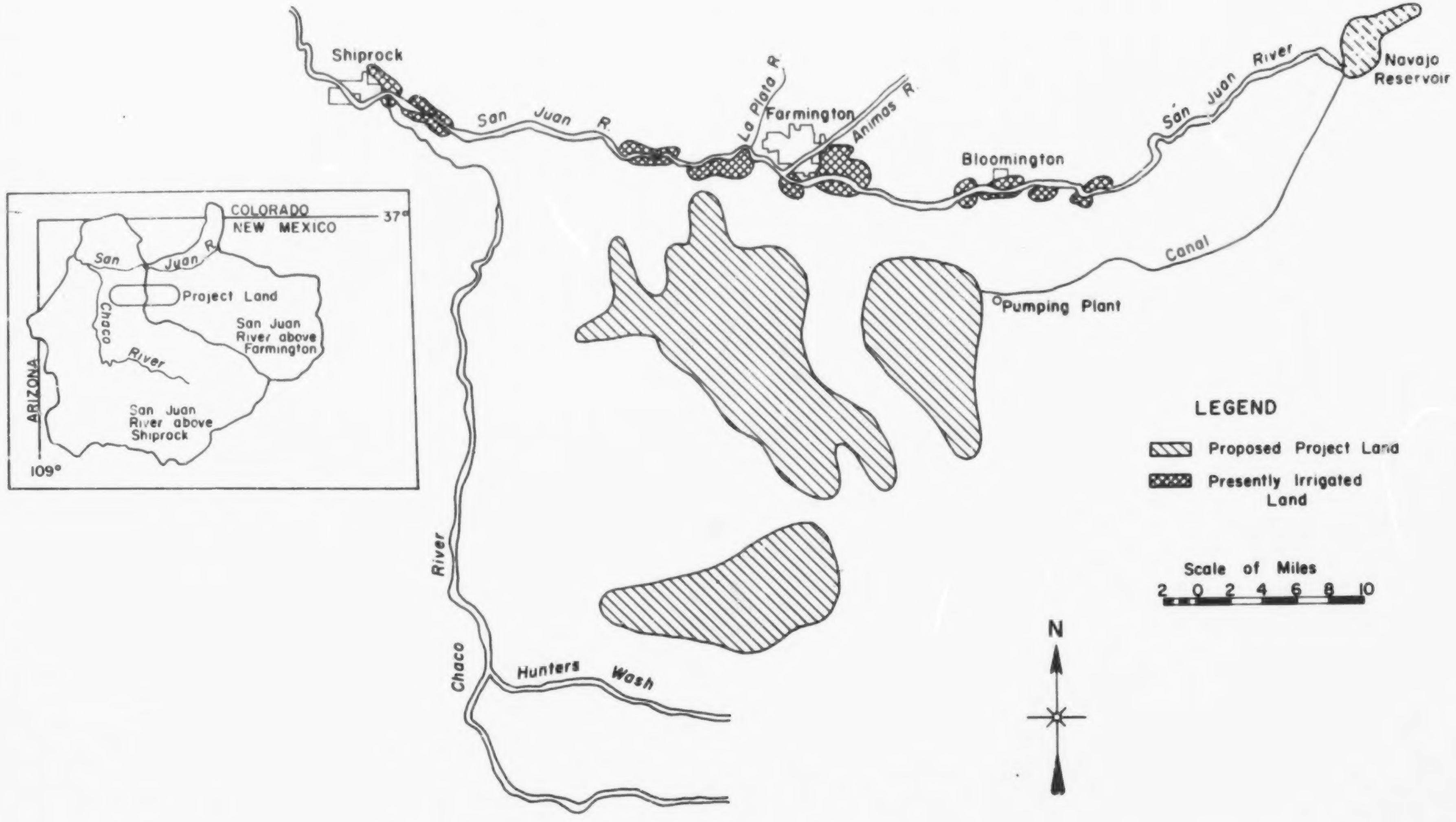

Shiprock
San Juan R
La Plata R
Farmington
Animas R
Bloomington
San Juan River
Navajo Reservoir
Canal
Pumping Plant
Chaco River
Hunters Wash
LEGEND
▨ Proposed Project Land
▩ Presently Irrigated Land
Scale of Miles
2 0 2 4 6 8 10
N
COLORADO
NEW MEXICO
37°
ARIZONA
109°
San
Juan R
Project Land
Chaco
River
San Juan River above Farmington
San Juan River above Shiprock

Figure 8.1. Location map depicting the proposed irrigation development for the Navajo Indians in north western New Mexico.

mately 33,100 acres would be served by a gravity canal system, and 77,500 acres would be supplied by the pump canal system. In total some 750 miles of main and supply laterals would be required to convey and deliver the water to the projected 1400 Navajo Indian farm units. Navajo Dam and Reservoir would be utilized to store the project waters.

To evaluate the effects of the proposed irrigation project, it is first necessary to develop a hydro-salinity model describing the area to be considered, basically from Bloomfield to Shiprock, New Mexico (Figure 8.1). This model should be based on the present day conditions existing within the basin. Once the model is developed, it then remains fixed and the proposed project is superimposed upon the model to evaluate the various changes in water quantity and salinity produced upon the system by the project. However, before discussing the hydro-salinity model of the basin and the proposed project, a brief description of some of the basin characteristics is given to aid in providing an understanding of the model development.

General description of basin

The San Juan River, the second largest tributary of the Colorado River, originates in the San Juan Mountain Range which forms the western slope of the Continental Divide in southwestern Colorado. Many of the peaks of this mountain range are over 13,000 feet in elevation. These peaks tower above the 5700 feet elevation of Navajo Dam or the 3300 feet elevation of the San Juan River at its confluence with the Colorado River. Because of their height the San Juan Mountains are the primary source of the river flows. High flows result from melting snows in the mountains, and these usually occur during the months of May and June. The major rivers originating within these mountains include the San Juan, Los Pinos, and Animas Rivers. The latter enters the model area directly whereas the other two rivers have already merged before flowing into Navajo Reservoir.

Navajo Dam is an earth and gravel fill structure with a height of 370 feet, crest length of 3750 feet, and crest elevation of 6090 feet. The associated spillway structure has a capacity of 22,100 cfs and operates at a crest elevation of 6068 feet. The reservoir has a maximum water surface elevation of 6084 feet, but normally operates between 5990 and 6068 feet elevation. This results in a normal working storage of 778,000 acre-feet. The total storage capacity, however, is equal to 1,450,000 acre-feet of water. The reservoir drains an area of 3240 square miles with a maximum recorded annual runoff of 2,257,000 acre-feet and a minimum annual runoff of 326,000 acre-feet. The average annual 1931-60 inflow to the reservoir would have been 965,000 acre-feet.

The average annual precipitation on the study basin is about 8.5 inches, most of which occurs during the summer months by way of thundershower activities. The average annual temperature of the proposed project area is 58 F. The climate is such that the average growing season consists of 185 days beginning April 15 and ending the middle of October. However, the average frost free period is approximately 160 days beginning about May 7. Within this study area, consumptive use computations are based on the 185 day growing season, as water is actually depleted for this time period.

In general, the San Juan River drains an area essentially underlain by friable sedimentary rock of the Cretaceous and Tertiary ages. However, in the upper reaches or headwaters of the principal tributaries, the underlying geologic formations consist of mostly volcanic rocks of the Tertiary age (Iorns et al., 1965). Some areas, the Animas and Los Pinos River basins, are underlain by large areas of igneous and metamorphic rocks of the Precambrian age. The proposed project area is underlain by three main formations, the Torrejon, Ojo Alamo sandstone, and McDermott (Bureau of Reclamation, 1966). The McDermott occurred first and was later covered by the Ojo Alamo, which in turn was overlain by the Torrejon. This geologic history results in a relationship between the three of erosional nonconformity, each being laid upon the eroded surface of the other. The Torrejon formation is the most prevalent of the three at the surface.

Insofar as a general topography is concerned, the area is that of a desert, dissected by many erroded canyons and arroyos. The lands are usually from 5000 to 7000 feet in elevation and are characterized by mesas, broad open valleys, buttes, and broad dry washes. The washes contain water only when the thunderstorms are of sufficiently high intensity to cause surface runoff. During such storms the water flowing in the canyons and arroyos transport large loads of silt. Two such streams in the model area are the Canyon Largo and Chaco River.

The soils within the basin are principally residuum created by the weathering of the underlying strata and as such are generally quite shallow and poorly developed. Iorns et al. (1965) states that where the underlying rock is shale, the residuum is relatively impermeable and high in soluble material, whereas for a parent rock of sandstone the residuum is permeable and low in soluble minerals. The river alluvium itself is a much better quality soil with few soluble minerals and good permeability in the upper reaches, but some of the lower reaches of the streams do contain relatively large amounts of soluble solids.

In general, vegative cover is sparse on all but the watershed areas. The predominant plant communities are blackbrush, greasewood, and big sage brush. However, in the majority of the desert areas, vegative cover is almost nonexistent with bare rock and ground often exposed. This accounts for the heavy sediment loads which result from thundershower activity.

The population of the area is generally distributed along the stream system. The two largest communities are Farmington, New Mexico, with a population of approximately 25,000 people, and Durango, Colorado, with about 12,000 people, which are located on the San Juan and Animas Rivers, respectively. Little industrial development is noted except for some uranium mills and petroleum production. Basically, the economy is founded on farming, tourist trade, and some stock raising.

Because the major portion of the San Juan River flows originate from melting snows and mountain springs, the water quality is generally good and suitable for most uses. Water in Navajo Reservoir, for example, averages about 150 ppm, has a sodium absorption ratio of about 0.75-1.00 and a boron concentration of about 0.10-0.20 ppm, and has a low salinity and alkalinity hazard.

Water quality measurements recorded at stations located downstream from Navajo Dam show a deterioration in the quality of the water. For example, the San Juan River at Shiprock, New Mexico, at low flow conditions reaches a dissolved solids concentration of about 1000 ppm. Further downstream near Bluff, Utah, the concentrations of dissolved solids of the San Juan River have reached levels exceeding 1800 ppm. These increases in salt concentrations are the result of return flows from agriculture areas, natural loading, and concentrating effects due to agriculture consumptive use.

For a proposed project to have a realistic application in the area under consideration, the scale of development must be within the confines of New Mexico's allocated share of Colorado River water. The original compact, as discussed in Chapter VI, allows New Mexico to deplete 11.25 percent of the remaining river water after the Lower Colorado River basin annual allotment of 7.5 million acre-feet is satisfied. Original estimates of the upper basin's share of water were equivalent to about 7.5 million acre-feet annually. However, more recent estimates indicate about 6 million acre-feet per year are available. The latter figure, which was felt to be more realistic for this study, would enable New Mexico to consume about 680,000 acre-feet per year from the San Juan River flows.

The proposed project would divert approximately this amount of water annually from the river, but would consumptively use only about 1/3 of it. Thus, another alternative discussed at a latter point in this chapter considers the effects produced by utilizing New Mexico's full allotment in various other ways.

Other proposed projects for utilizing the portion of Colorado River water allotted to New Mexico include the San Juan-Chama project, extension to the existing Pine River project, Hammond project, and additional municipal and industrial development. For this study, consideration was given to only the Hammond project, currently under construction, with an estimated annual depletion of 8500 acre-feet (Bureau of Reclamation, 1966).

Analog hydro-salinity model of the basin

Development of the simulation model of the drainage area from the San Juan River at Archuleta to Shiprock, New Mexico, followed the same approach and reasoning that was outlined in the last section of Chapter VI by a thorough discussion of the White River subbasin. However, for clarification purposes some further points are outlined in the following paragraphs.

Before the effects of the proposed irrigation project can be determined, a model must be developed which describes the system as it now exists. Verification of the model representing the present system determines the model system coefficients or parameters which are held constant during studies of the proposed project. Changes between the two systems are reflected in the input data which essentially superimposes new project conditions upon the old system.

As discussed earlier (Chapter V), the basis upon which the inflows to the system are considered and computations are made in the computer model is depth units (inches) over the area of the agriculture lands and the tons of salt dissolved within each inch of water over the agriculture lands. To evaluate the effect of an increased irrigated acreage merely involves rescaling the inputs of water and salt so they are spread over the larger area of agriculture land. Differences resulting from the project are then determined by comparing model outputs under pre-projects and post-project conditions.

The geographical area simulated by the hydro-salinity model is shown by Figure 8.1. The model is essentially a combination of two models developed in Chapter VII, which were designated as (1) The San Juan River above Farmington, New Mexico, and (2) the San Juan River above Shiprock, New Mexico. The area drained by these two subbasins was combined and treated as a single unit in the development of this model because the lands proposed in the project for irrigation are located in both of these two subbasins.

The agriculture lands considered in the models presently consist of 10,400 acres and 12,300 acres located in San Juan River above Farmington, and Shiprock, New Mexico, subbasins, respectively. This acreage of 22,700 acres forms the basis for developing the model of the system without the proposed project. To determine the project effects, the agriculture area was increased to 127,700 acres, which includes both the 22,700 acres presently irrigated as well as an additional

105,000 acres proposed by the project. Note the project proposes development of 110,600 acres of which only 105,000 are considered in the model. The assumption was made that about 5 percent (5600 acres) would usually be idle, in farmsteads, or wasteage, and only 105,000 acres would be effectively irrigated.

Because of data availability, the years selected for calibrating the hydro-salinity model of the area were 1964 and 1965. The hydrologic and salinity inflows to the system consist of the combined inputs listed in Table D-3 (Appendix D) for the San Juan River above Farmington and Shiprock, New Mexico, subbasins. To reiterate, these include the surface and subsurface flows at the San Juan River near Archuleta, Animas River, and LaPlata River. The model developed for the San Juan River above Archuleta indicated no subsurface outflow from that system or groundwater input to the project area from the upstream subbasin.

The climatological stations forming the basis for precipitation and temperature inputs to the system consisted of those located at (1) Farmington, (2) Farmington AP, (3) Bloomfield, (4) Fruitland, and (5) Shiprock, New Mexico. Each station was equally weighted because of its uniform distribution throughout the agricultural area.

The precipitation data used for correlation purposes (Equations 3.4 and 4.6) were obtained from a numerical average of the data collected at the weather stations in Bloomfield, Chaco, and Otis, New Mexico. Examination of the records indicated a time delay of approximately 2 to 4 days from the actual time of rainfall until the runoff water was reflected at the outflow point of the basin (San Juan River at Shiprock, New Mexico). Because the time resolution of the computer program does not consider such short time increments, the model developed for this system was refined by delaying for three days, through hand calculation, the water contributed as ungaged inflow from the precipitation correlation.

Due to the abundant supply of water compared to the present demand for its use, measurement of water diversions to agriculture lands has never been required. The State of New Mexico, which follows the appropriative doctrine for water rights, legally restricts such diversions to 3.0 acre-feet per acre as measured at the farm headgate. Based on this restriction, the estimated diversion requirement at the stream averages 5.0 acre-feet per acre and has been utilized to determine the volume and rate of water diverted by canals for agricultural use in the system. Since the time distribution of the water is not known for this portion of New Mexico, the water was allocated basically in accordance with the plant requirements.

The distribution of crop varieties was assumed to be a weighted average of that indicated in Table F-3 (Appendix F) for the San Juan River above Farmington and Shiprock, New Mexico, subbasins. The weighting procedure was based upon the portion of agriculture land contributed to the 22,700 acres by each of the aforementioned subbasins. The depletion due to phreatophytes was accounted for by adding together the areas for each of these two subbasins.

The tonnage of salts contributed from natural sources was estimated from procedures outlined earlier. The contribution of salts obtained from this source was estimated to be essentially a constant tonnage on both a monthly and yearly basis regardless of the discharge (Equations 4.14 and 4.15) from the basin. This situation occurs in only one or two other subbasins in the whole Upper Colorado River basin.

The actual data inputs to the analog computer model from (1) the various rivers, (2) canal diversions and their distribution over time, (3) combined input salinity concentrations, (4) precipitation, (5) temperature, (6) combined crop growth stage coefficient, (7) percentage of surface water - interchanged with the groundwater system to estimate natural salt loading, and (8) outflow of water and salt as measured at the San Juan River near Shiprock, New Mexico, station are tabulated in Table I-1 and I-2 of Appendix I for 1964 and 1965.

Verification of analog model

To illustrate the reliability of the model for simulating the physical system, a comparison of the observed and computed outflow of water and salt flow for 1964 and 1965 is shown in Figures 8.2 and 8.3. Close agreement is realized between the monthly values of the computed and observed outflow hydrographs of water. Over the whole year, the accumulative outflow of water is within one-half percent of the observed value for both 1964 and 1965. The computed and observed salt outflow graphs maintain good agreement with the exception of August, 1965, and July, August, and September, 1964. The explanation given for the deviation between observed and calculated values is the inadequacy of the salinity model to properly describe the ungaged salt loading resulting from thundershower activity in the southwest portion of the basin. These storms produce an erosive action that contributes significant quantities of ungaged salt to the system, probably originating within the sediment load transported by the runoff water. Obviously, the salt and sediment loading vary considerably depending upon the location of the rainstorm. No difficulty occurs in describing the hydrologic system, but using a fixed ungaged salinity concentration, as in this model, does not allow a good simulation of this phenomenon. However, insufficient data preclude the justification of any other logical assumption.

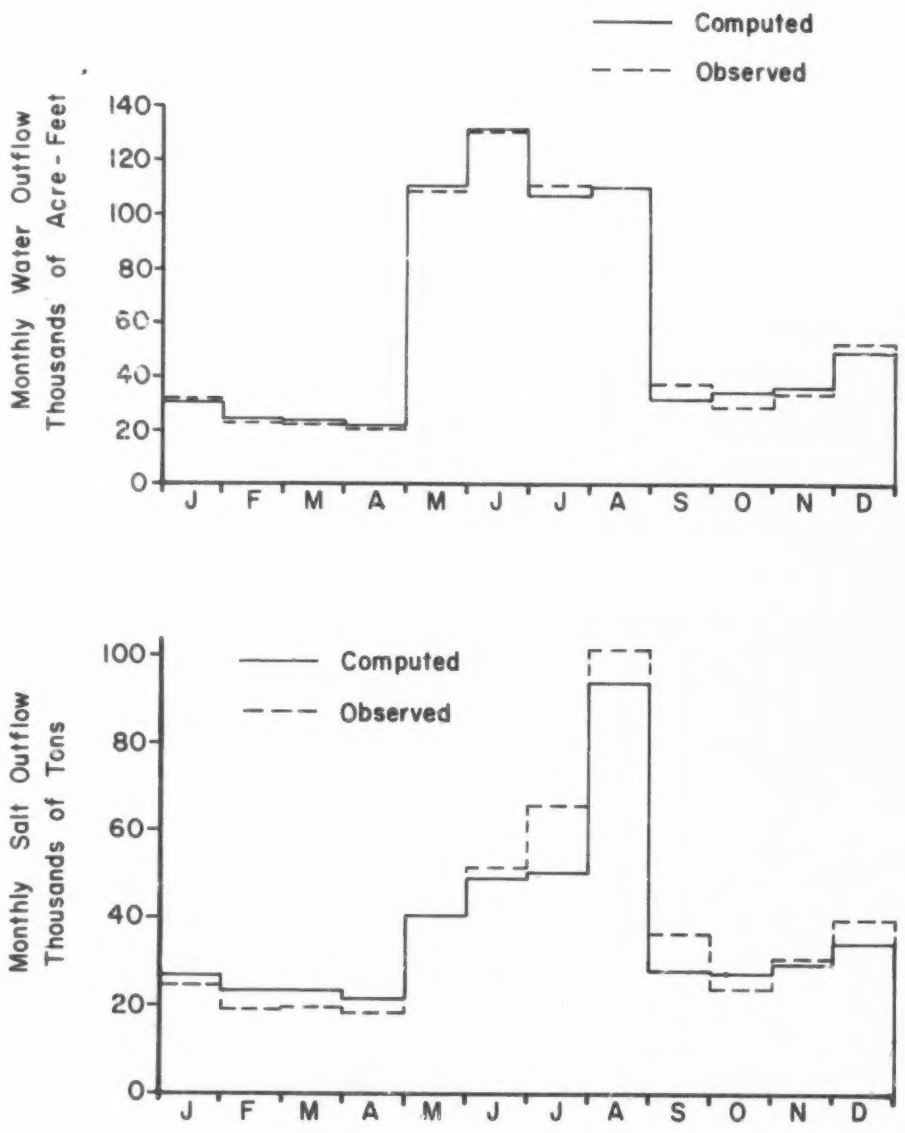


Figure 8.2. Comparison between the 1964 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico, without the proposed project.

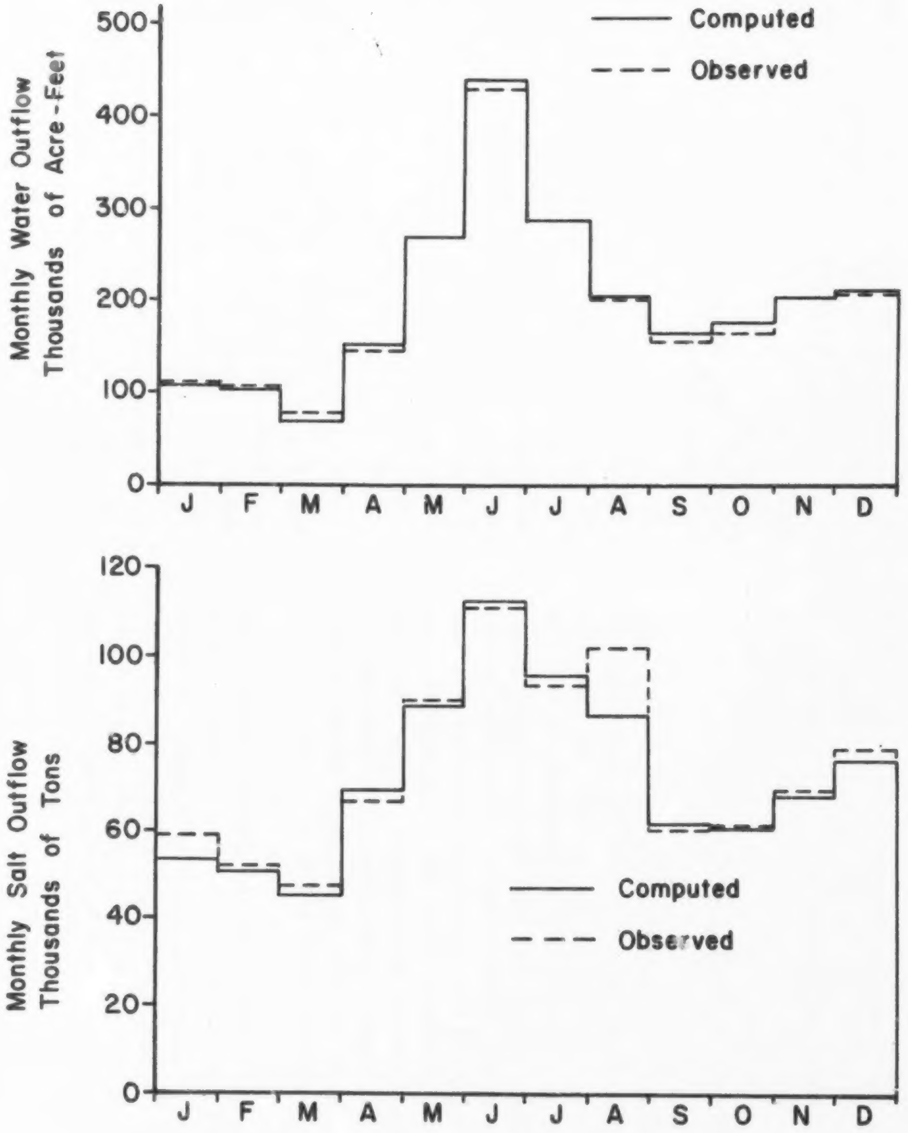


Figure 8.3. Comparison between the 1965 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico, without the proposed project.

Table 8.1 indicates the values of the model parameters developed during the verification procedure. This set of coefficients was utilized to determine the computed outflow graphs in Figures 8.2 and 8.3. Since these graphs indicate the model adequately describes the system or management area, the model becomes fixed and the coefficients indicated in Table 8.1 remain constant.

The model indicates an annual cropland evapotranspirational use of about 62,500 acre-feet in both 1964 and 1965, or a depletion of about 2.75 acre-feet per acre. The 5500 acres of phreatophytes consume about 24,000 acre-feet of water each year. This amounts to a depletion of approximately 4.5 acre-feet per acre.

The volume of ungaged water inflow to the basin was computed to be 38,200 acre-feet in 1964 and 31,200 acre-feet in 1965. These waters transported 48,500 and 37,500 tons of salt in 1964 and 1965, respectively. The average annual salt load resulting from natural sources was computed to be approximately 135,000 tons with a deviation between years of no more than 4 percent of this value.

The salt contribution computed to originate within the agricultural system was equivalent to 15,000 tons in 1964 and 20,000 tons in 1965. Stated in another way, the average agricultural salt contribution is equivalent to about 0.65 tons per acre of irrigated land per year.

The effects of the agricultural system upon the concentration of total dissolved solids are twofold. One is the concentrating effects resulting from the same tonnage of salt being transported by a flow of water reduced through consumptive use depletion on the cropland. The other factor which increases the salinity concentration is the increase in salt load which occurs as the irrigation water dissolves additional soluble salts. The annual salinity concentration of water leaving the basin in 1964 without the proposed project was 449 ppm (parts per million). The hydro-salinity model indicates that this salinity level would have been only 405 ppm under natural conditions, since the agricultural system increased the value by 44 ppm. An increase in salt loading contributed 12 ppm and evapotranspiration caused the remaining 32 ppm. In 1965, similar values were 10 ppm from salt loading and 10 ppm from consumptive use causing the annual salinity concentration to increase from 245 ppm to the measured value of 265 ppm. These are annual figures, whereas monthly values would show a greater variation.

The model, which was calibrated as described above with data for 1964 and 1965, was subsequently tested with data for 1966. For this test the model parameters were set at those values indicated by Table 8.1. The conditions existing within the system at the end of December 1965 were utilized as the initial conditions for the beginning of 1966. The computer output and observed water and salt outflow graphs for 1966 are illustrated in Figure 8.4. Computed graphs of water and salt on a monthly basis show compatibility in essentially every month with the observed hydrographs of flow. The computed cummulative monthly values of water and salt are within 2 1/2 percent of the observed values.

The annual depletion of water from the basin by both crops and phreatophytes agrees closely with the yearly consumptive use in 1964 and 1965, although evapotranspiration from the cropland was about 3000 acre-feet higher.

The addition of water and salt from ungaged sources was about 5000 acre-feet, and 8000 tons, respectively, much lower than in 1964 or 1965. The drop in ungaged water and salt contribution aids in explaining the better fit obtained between the observed and computed hydrographs for this year.

The contribution of salt from natural sources was 134,000 tons, whereas the load from the agricultural system was 14,000 tons. Both values agree with those occurring from the same sources in 1964 and 1965.

The annual total dissolved solids at the basin outflow were computed to be 300 ppm including 10 ppm due to cropland consumptive use and 8 ppm due to increased salt loading for a computed agricultural effect of 18 ppm on the system.

Modeling average data

To provide a further insight into the system being considered in this chapter, an "average" condition was investigated. This average condition considered mean monthly values for the time period 1931-60, but with flow conditions modified to those of 1965. The conditions existing in 1965 were considered to include the effects of Navajo Reservoir in the analysis since this facility was incorporated into the hydro-salinity model as developed. The only problem encountered in this approach was the correct estimation of average monthly inflows and associated salt loads to the basin as released from Navajo Reservoir.

The procedure utilized in obtaining reservoir releases, which are inputs to the management area, was an operation study of the reservoir from 1931 to 1960. The operation study followed closely a similar study made by the Bureau of Reclamation (1966). Computation of evaporation losses, reservoir capacity, reservoir spills, and outflows were treated in the same manner in both studies. Two differences are noted between the two studies, however.

Table 8.1. Single constant input parameters or coefficients for management area above Shiprock, New Mexico.[a]

Symbol	Description	Value
$k_u^{\bullet}$	coefficient relating the rate of unmeasured inflow to a system to a measured inflow rate	0.0
k_a	coefficient relating the rate of unmeasured surface inflow to the precipitation rate	0.205
k_b	coefficient relating the rate of unmeasured surface inflow to the rate of melting snow storage	0.0
k_c	coefficient relating the rate of unmeasured groundwater runoff to a surface runoff rate	0.0
k_s	a constant applied in the computation of snowmelt rate	0.20
Eff	water conveyance and application efficiency	55%
M_{es}	limiting value of available soil moisture applied in computation of evapotranspiration	2.0 inches
M_{cs}	available soil moisture storage capacity	5.5 inches
k_d	average percentage of total outflow leaving as subsurface flow	0.0%
C_g	average salinity concentration within the groundwater basin	1,000 ppm
C_s	factor which increases the average salinity concentration of the surface flow as it returns from the irrigated lands	1.20
C_{ga}	average salinity concentration within the groundwater system of the agriculture area	780 ppm
C_{og}	average salinity concentration of subsurface water leaving the system at the outflow point	
n	intercept on the y-axis of a log-log plot of percent interchange and flow when the latter equals 1.0 cfs (Equation 4.4)	350.5
m	the slope of a line on log-log plot relating percentage interchange and flow (Equation 4.4)	-1.07
Pot 5	threshold at which the precipitation correlation becomes effective	1.32 inches
Pot 21	initial condition for snow storage	0.15 inches (1964) 1.12 inches (1965)
Pot 24	initial condition for soil moisture content	3.5 inches (1964) 4.4 inches (1965)
Pot 28	initial condition for deep percolating flows	0.05 inches (1964) 0.04 inches (1965)
Pot 30	initial condition for groundwater outflow	0.0 inches (1964) 0.0 inches (1965)
Delay A	time of delay before deep percolating flows appear at outflow point	3.5 months
Delay B	time flows within the system are delayed before leaving the basin as subsurface outflow	

[a] All values expressed in inches refer to depth over the irrigated land.

In the study reported herein inflow to the reservoir was taken as the 1931-60 estimated average monthly flow of the San Juan River near Archuleta, New Mexico. These estimated flows, because of more recent data, were obtained by correlation procedures utilizing the digital computer program found in Appendix D. The flow of the San Juan River at this point serves as the inflow to Navajo Reservoir. In the Bureau of Reclamation (USBR) study reservoir inflows were estimated from measured flows of the San Juan River near Blanco with some additional assumptions. The USBR study assumed no base reservoir release whereas the operation study of this report assumed a base monthly release of 10,000 acre-feet. Additional outflows from the reservoir included in both operation studies were spills from the reservoir and the annual release of 30,000 acre-feet of water to satisfy the existing downstream water rights.

The operation study provided an estimate of the average monthly releases from Navajo Reservoir, or the inflow to the basin contributed by the San Juan River, as well as an estimate of the average 1931-60 monthly change in storage of the reservoir. The average 1931-60 monthly flows of the San Juan River at Shiprock, New Mexico, were adjusted by the mean monthly change in reservoir storage to form an estimate of the outflow from the basin based on present day (1965) conditions. These outflow values were treated as the recorded or observed outflow from the basin for the 1931-60 average condition.

Estimation of the total dissolved solids concentrations associated with the mean inflows and outflows to the basin was another problem in evaluating the system on an average basis. The average concentrations associated with the inflows to the system from Navajo Reservoir were obtained by averaging the available records for this source (1962 to 1967) and assuming they were applicable for the 1931-60 time period. Though not entirely correct, it was felt this assumption was more correct than assuming a constant concentration within the reservoir. The salinity records on the Animas and LaPlata Rivers were long enough to provide estimates of long term averages. Through a weighting procedures, an average monthly long term salinity concentration was developed for the combination of all surface inflows. To obtain the dissolved solids concentrations associated with the water flow at the Shiprock station, the average monthly value for the length of the station record was assumed to apply. Although the preceding assumptions are not entirely correct, they serve as approximations in view of limitation data.

The remaining input values, which were needed to simulate an average condition within the basin, included inflows contributed from the Animas and LaPlata Rivers, precipitation, and temperature. The values used for (1) crop and phreatophyte land areas, (2) canal diversions, (3) correlation stations, except the Otis station, (4) crop growth coefficients, and (5) moisture holding capacities were assumed to be the same as those used in the model for 1964 and 1965, since little information on a long term basis was available for these parameters.

A summary statement of all forementioned parameters and values for average conditions (1931-60) is tabulated in Table I-3 (Appendix I), including the monthly average present day flows released from Navajo Reservoir (San Juan River at Archuleta), the basin outflows, and salinity concentrations.

These average values were input to the hydro-salinity model developed for this basin area with all model coefficients and parameters remaining fixed at the value indicated in Table 8.1. The resulting outflow plots of water and salt from the computer as well as the observed values, as adjusted by the operation of Navajo Reservoir, are illustrated in Figure 8.5.

Both the computed water and salt outflow graphs (Figure 8.5) indicate close agreement with the observed plots. Deviations were expected mainly because of the assumptions made in the determination of the inflow and outflow values to the model.

Average cropland consumptive use is estimated to be 60,000 acre-feet annually, whereas the same depletion by phreatophytes is 24,200 acre-feet. The average annual volume of water diverted to the agriculture area is 125,000 acre-feet, or a little over 5 acre-feet per acre per year. The average annual ungaged inflow to the system is 2800 acre-feet of water, transporting 3700 tons of salt. The salt load from natural sources averages 127,000 tons annually, and the agricultural system contributes 10,000 tons. Evapotranspiration is responsible for a 15 ppm increase in the average annual outflow concentration of 350 ppm, whereas salt load from the agricultural system increases the average outflow salinity level by 6 ppm.

Predicted effects of project

Based on the good agreement that was achieved between the computed and observed outflow functions of water and salt (Figures 8.2, 8.3, 8.4, and 8.5), it was felt the hydro-salinity model of the management area was adequate to indicate realistic responses created by the proposed irrigation project.

Restated briefly, under the proposed project Navajo Reservoir is used to store water to irrigate an additional 110,000 acres of land of which 105,000 acres are assumed to be fully utilized. The model with the proposed irrigation project is based on an agriculture land area of 127,700 acres. Modeling the effects of this proposed project involves rescaling the volumetric inputs to inches of water and tons per inch salt content over

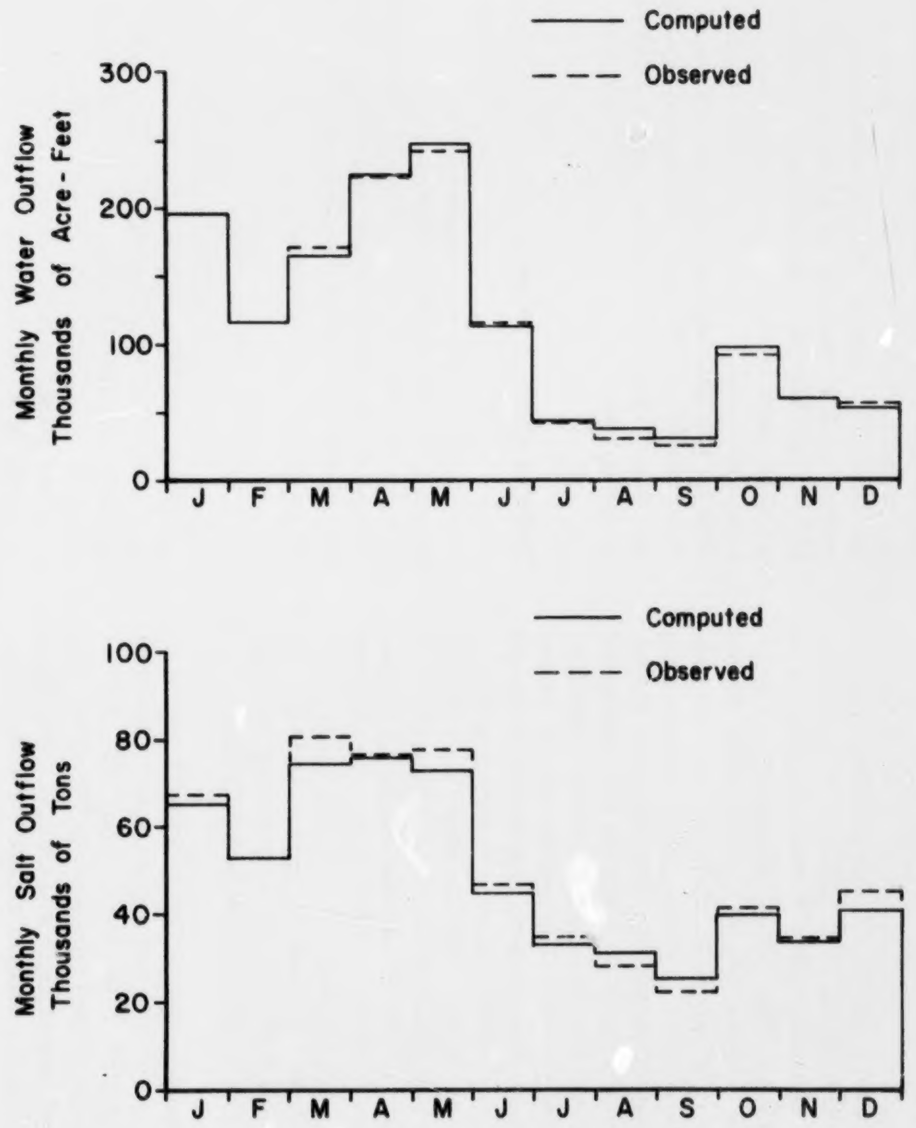


Figure 8.4. Comparison between the 1966 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico, without the proposed project.

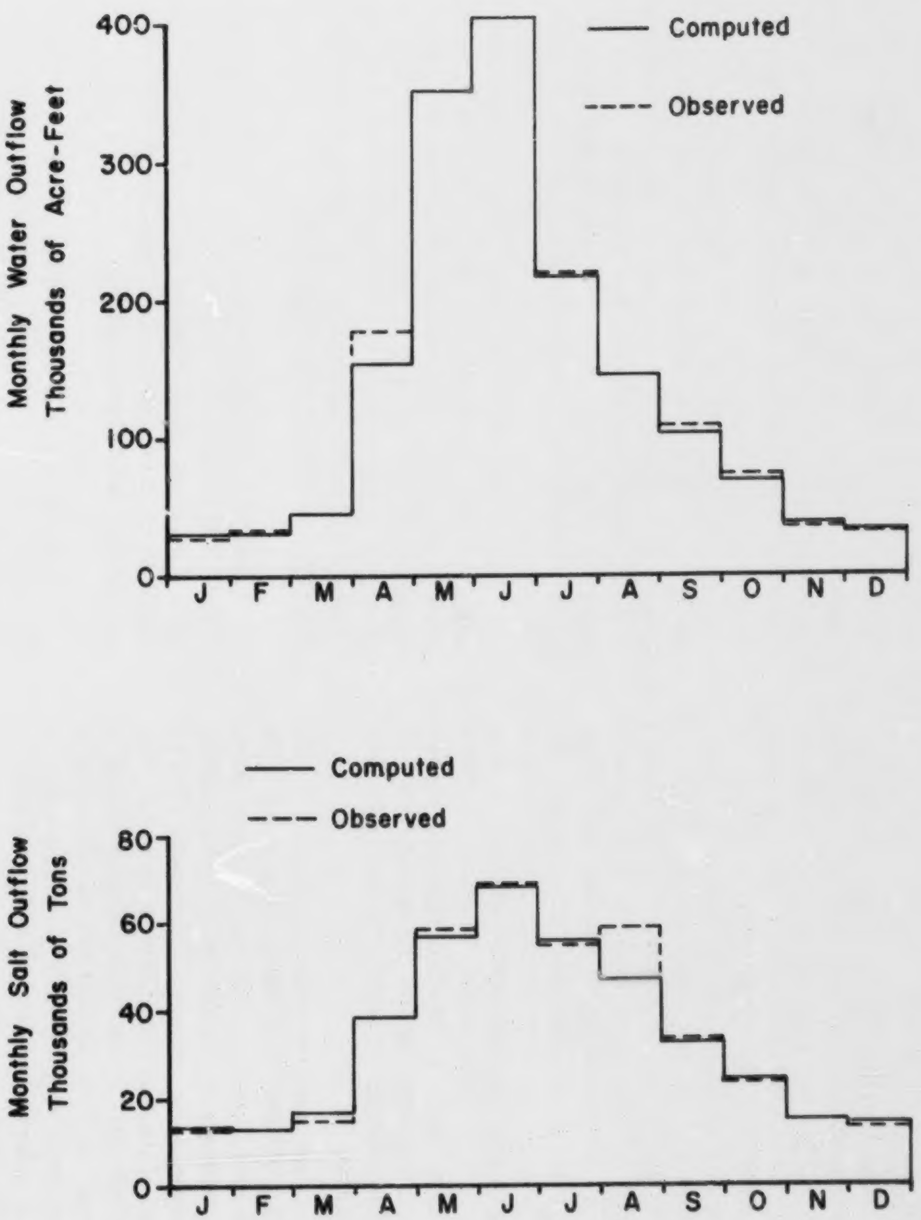


Figure 8.5. Comparison between the 1931-60 computed and observed monthly outflow of water and salt from management area above Shiprock, New Mexico, without the proposed project.

the new land area. The model is still fixed by the same coefficients determined during the verification procedure, as tabulated in Table 8.1.

To illustrate the changes made in magnitude scaling, the computer inputs to the model, which describe the proposed project, have been tabulated in Table I-4 in Appendix I for average monthly conditions during 1931-60. Note the parameters of precipitation, temperature, percent daylight hours, precipitation correlation, and water inflow in acre-feet have identical values to those tabulated for the model without the proposed project in Table I-3. The voltages representing surface water inflows and input salinity concentrations in Table I-4 are rescaled and different from those in Table I-3 to reflect the increased area in agricultural land. Groundwater salinity concentrations were maintained at the same level, but required new potentiometer settings to be compatible with rescaling the input voltages. The crop growth stage coefficients in Table I-4 differ slightly from Table I-3 because of the different cropping pattern predicted for the 105,000 acres of additional land area. Actually, little difference exists between the crop distribution of the present agricultural area and that proposed for the 105,000 acre land tract. The cropping pattern used for the proposed development consists of 35 percent alfalfa, 15 percent pasture, 20 percent corn, and 10 percent each of orchards, small truck crops, and potatoes (Bureau of Reclamation, 1966). The k_c values for phreatophytes are rescaled to reflect the increased area in agriculture lands. The canal diversions indicated on Table I-4 were obtained from the reservoir operation study discussed earlier in this chapter. Based on 1931-60 climatological conditions, average annual diversions to serve both existing and proposed project lands are 750,000 acre-feet. The only other factor which varies in the model simulating the proposed project is the initial condition within the groundwater system of the agricultural area. The model, modified as described above to include the proposed project, was also operated using input data for the years 1964, 1965, and 1966. Irrigation diversions during this run were established in accordance with crop needs and the quantity of water. The only parameter, which was available in the system and amounted to 580,000 acre-feet or 4.6 acre-feet per acre in 1964, 750,000 acre-feet or 5.8 acre-feet per acre in 1965 and 490,000 acre-feet or 3.9 acre-feet per acre in 1966.

To illustrate the effects of the proposed irrigation project, comparisons have been made between the outflow graphs from the basin with project conditions and without project conditions for the years 1964, 1965, 1966, and average of 1931-60 as shown in Figures 8.6 through 8.9. The graphical illustration provided by these figures indicates the differences the project would have made on the water and salt outflows from the basin for the indicated years. The differences are easily explained utilizing plotted output from various points within the computer program to provide estimates of the magnitude of the additions or depletions of water and salt from the system. Then plots indicate that outflow rates from the system are generally reduced during the summer months by project conditions. The months for which this statement is not true are the fall and winter months with a greater outflow under project conditions as a result of the delayed return flow water and salts from the agriculture groundwater system.

On an annual basis, the total computed water outflow from the basin is much lower with the project than without it, because of the increased evapotranspiration depletion in the system. The computer estimate of the cropland consumptive use with the project is 311,000 acre-feet, 325,000 acre-feet, 295,000 acre-feet, and 327,000 acre-feet in 1964, 1965, 1966, and 1931-60, respectively. Noted earlier was an estimated average annual depletion due to cropland consumptive use of 62,500 acre-feet or 2.75 acre-feet per acre without the project. When the proposed project is imposed upon the system, it appears the annual depletion would increase to an average of 325,000 acre-feet or 2.5 acre-feet per acre. The 1964 and 1966 computed depletion estimates are lower than this average figure because lower volumes of water were diverted to the crops during these years.

On an annual basis, the total computed salt outflow from the basin is higher with the proposed project than without it, although the time distribution is different (Figures 8.6 through 8.9). The increase in salt loading comes from the agricultural system, since the gaged and ungaged inflows and load from natural sources remain the same with or without the proposed project. The salt load from natural sources, essentially a constant tonnage, was still maintained as a function of the basin outflow both with and without the project. The average annual outflow of salt from natural sources was about 135,000 tons without the project. Under project conditions the computed values of salt load from natural sources were 135,000 tons, 140,000 tons, 137,000 tons, and 129,000 tons in 1964, 1965, 1966, and mean 1931-60, respectively.

The salt load contributed from the agriculture system ranged from 16,000 tons in 1964 to 70,000 tons in 1965. The tonnage estimated for the 1931-60 mean was 45,000 tons. Both 1964 and 1966 had comparatively low salt loads, approximately 0.15 tons per acre per year, returning from the irrgated lands of the system. These low values would indicate storage or accumulation of salt in the agriculture soils during these years. One underlying assumption of the salinity model is that a salt balance is maintained. From various other plots from the computer, it is estimated that the salt deposition each of these two years was approximately 35,000 tons. Assuming this approximation is correct, the salt load from the irrigated area would have been about 0.45 tons per acre per year in 1964 and 1966, compared to the

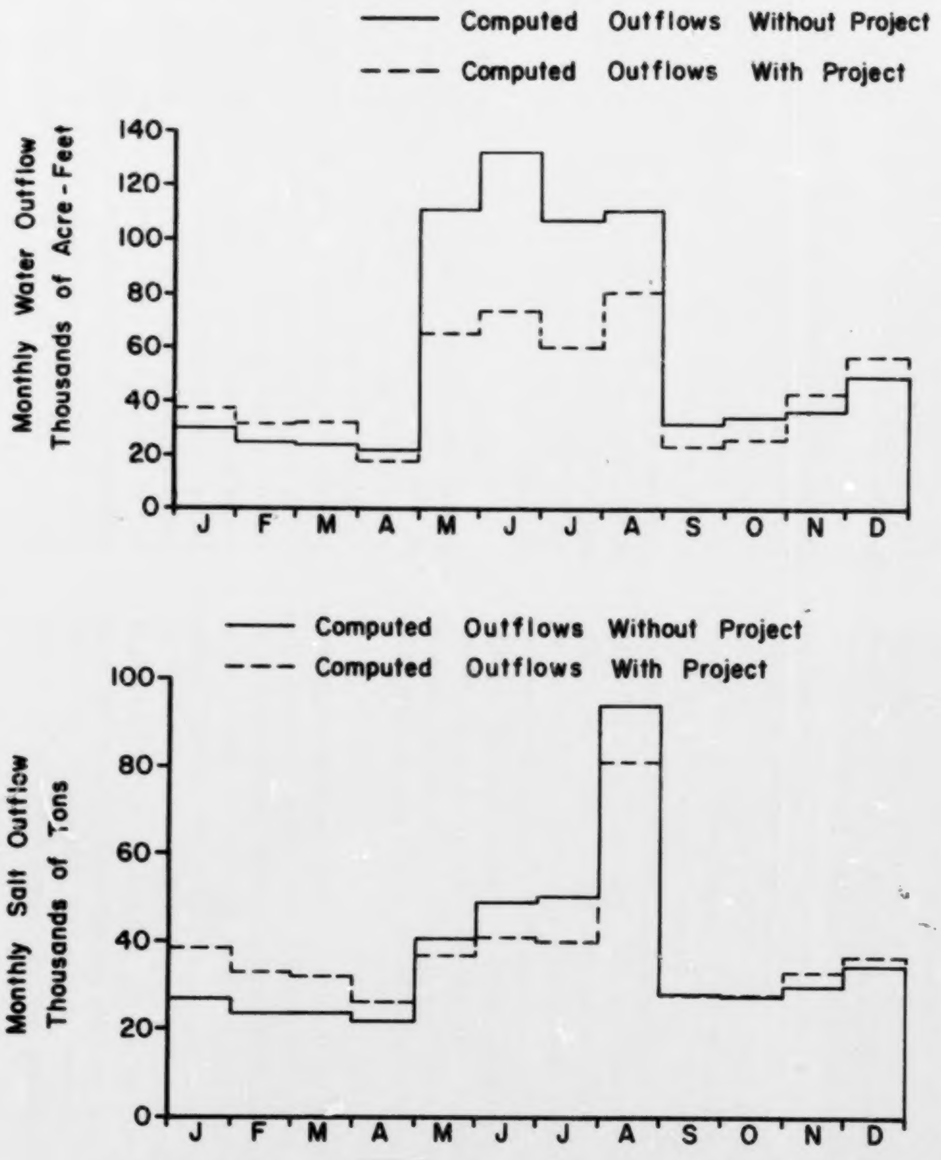


Figure 8.6. Comparison of the basin outflow hydrographs of water and salt for 1964 with and without the proposed irrigation development.

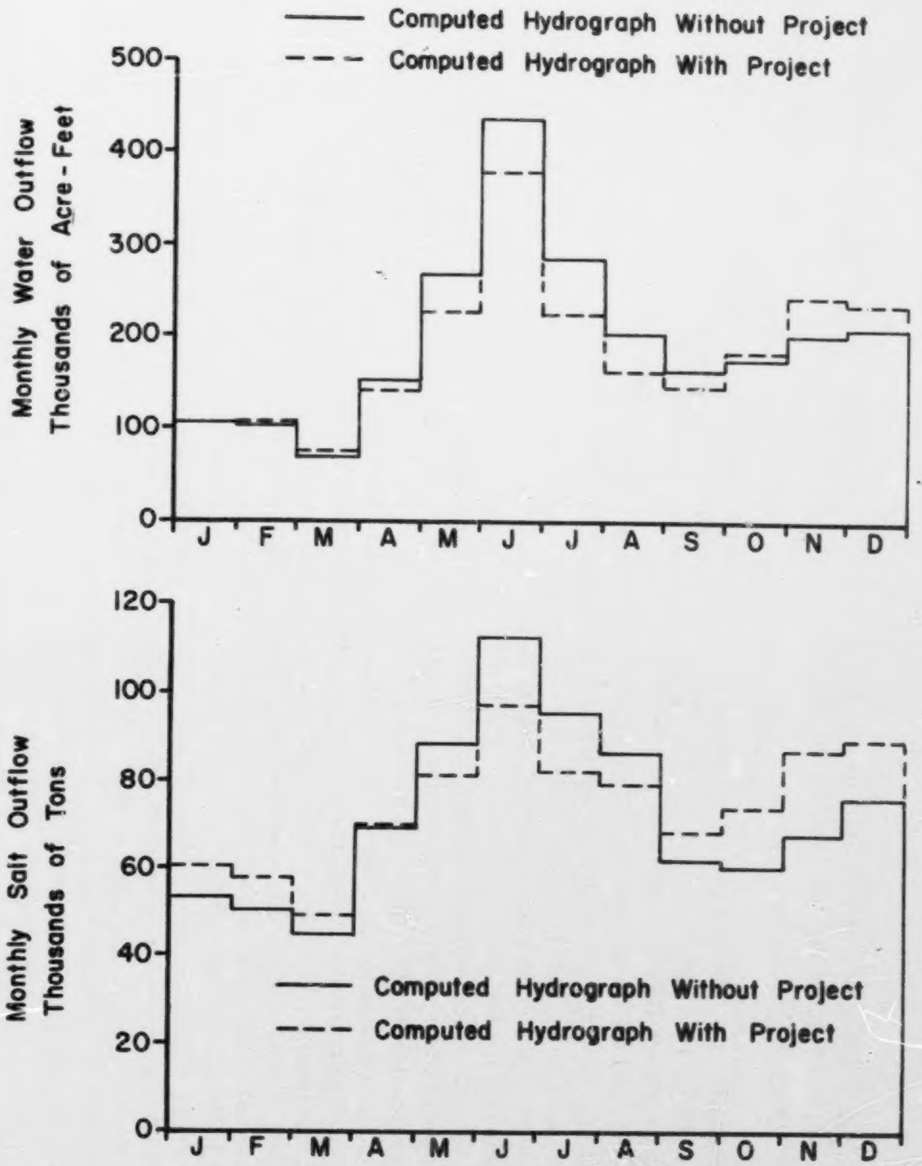


Figure 8.7. Comparison of the basin outflow hydrographs of water and salt for 1965 with and without the proposed irrigation development.

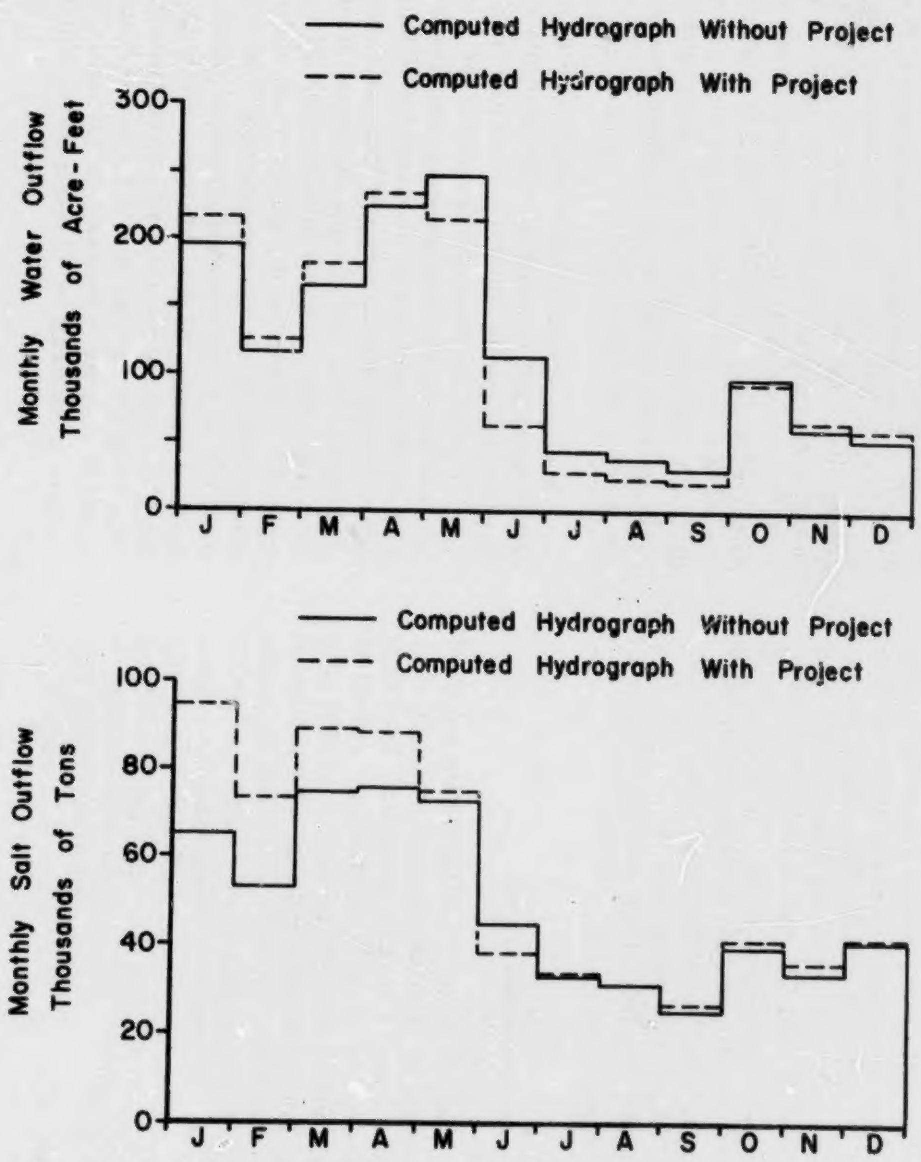


Figure 8.8. Comparison of the basin outflow hydrographs of water and salt for 1966 with and without the proposed irrigation development.

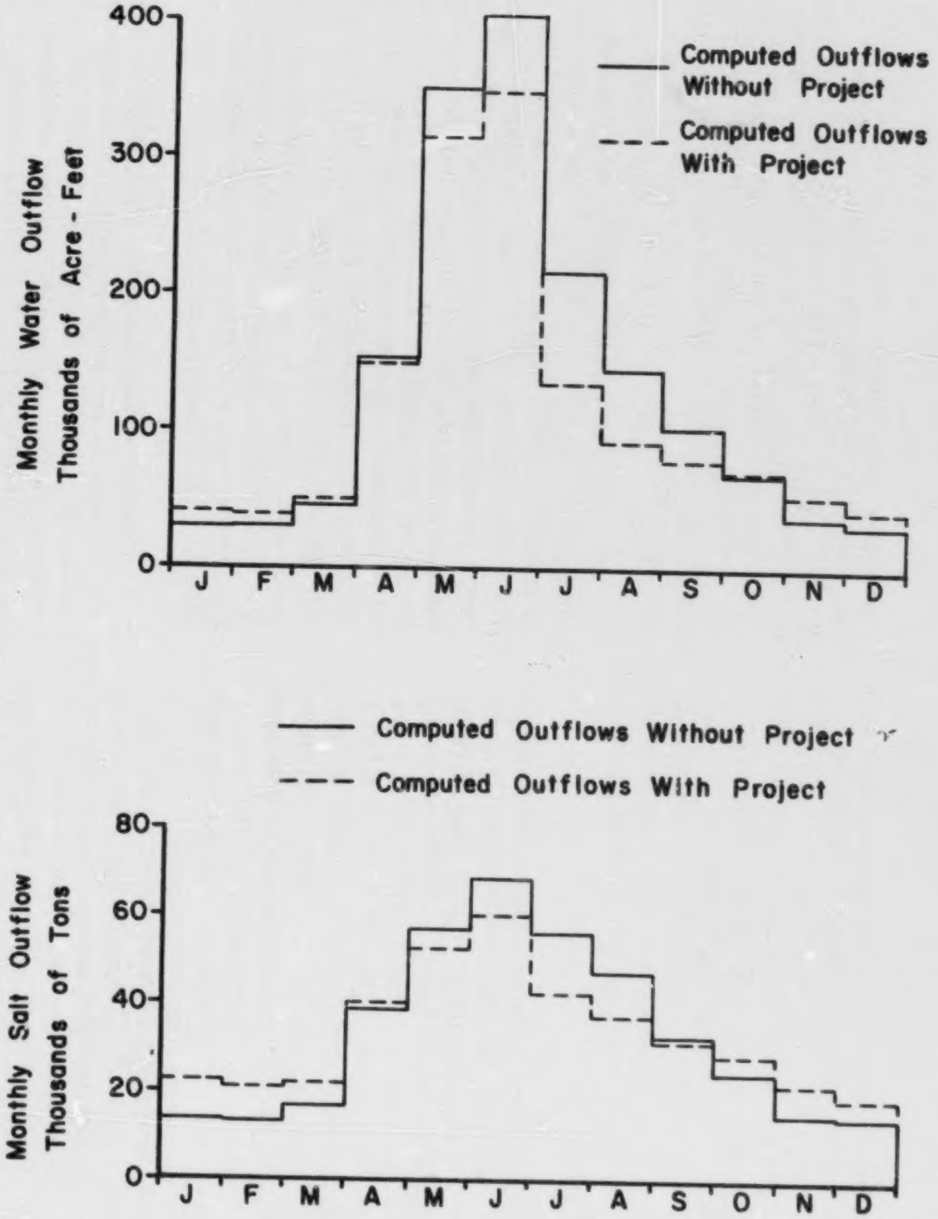


Figure 8.9. Comparison of the basin outflow hydrographs of water and salt for 1931-60 with and without the proposed irrigation development.

computed salt load 0.55 and 0.40 tons per acre per year in 1965 and the 1931-60 period, respectively. The slight deviation in these values may be partially explained by the large scale factor within the salinity model for this system wherein one volt equals about 4000 tons of salt. The error of one or two volts would easily account for thousands of tons of salt. Nonetheless, it appears that a salt load of about 0.5 tons per acre per year either with or without the project is the salt load contributed from the agricultural system.

The proposed project would increase the dissolved solids concentration at the basin outlet primarily from depeltion by evapotranspiration. A great deal of variation in the salinity level does occur, however, depending upon the rate of water discharge. In 1964, which was a year of short water supply (800,000 acre-feet inflow), cropland consumptive use would have increased the outflow salinity concentration by 255 ppm, whereas in 1965 (2,500,000 acre-feet inflow) the effect would have been only 40 ppm. On the average (1931-60) the concentrating effects of agriculture evapotranspiration would be about 90 ppm. The increase in salinity concentration attributable to the salt load from the agriculture system would have been 12 ppm in 1964, 25 ppm in 1965, and 22 ppm for the average annual 1931-60 period. As noted earlier, the 1964 value is low due to salt accumulation that year. Comparable values without the proposed project are 10 ppm and 6 ppm for agricultural salt loading in 1965 and the average annual 1931-60 period, respectively. For the same two periods salinity increases without the project due to the concentrating effects of evapotranspiration are estimated to be 10 ppm and 15 ppm, respectively. The salinity concentrations at the outflow point of the system would have been 405, 250, 285, and 335 ppm in 1964, 1965, 1966, and for 1931-60, respectively, if the effects of agricultural systems were removed from the basin. Furthermore if natural loading of salt were eliminated from this basin, the outflow salinity level would drop to 325, 220, 235, and 295 ppm in 1964, 1965, 1966, and 1931-60, respectively.

Alternative variations within project

In the analysis of the preceding section several of the model parameters were assumed to be unchanged by the proposed expansion of the irrgated land. For example, the groundwater salinity level within the agriculture groundwater system was determined to be 800 ppm when the model was verified, and this value was used in the preceding analysis. If under project conditions this concentration was increased to an equilibrium level of 1200 ppm, the salt load contributed from the irrigated area would be 120,000 tons in 1965, and an average annual amount of 95,000 tons based on the 1931-60 period. If the salinity concentration were increased to 1600 ppm, the salt load would be 190,000 tons in 1965 and 140,000 tons for 1931-60 period. Should the groundwater concentration level rise as high as 2000 ppm, the salt load from the irrigated area would be 260,000 tons in 1965 and a mean of 190,000 tons for the 1931-60 period. These figures represent an increase in salt load of 190,000 and 145,000 tons for 1965 and the 1931-60 period, respectively, over the salt load computed under project conditions with a groundwater concentration of 800 ppm.

The salt load from the irrigated area might also be attributed to the overland flow and interflow segments of return flow. If, for example, it were assumed that in 1965 these segments of the irrigation return flows dissolved no additional salts (and that the groundwater salinity concentration level remained at 800 ppm), the salt load from the agriculture area would have been reduced by approximately 25,000 tons. However, if this segment of return flow increased its salt load by 50 percent through the solution of additional salts, the salt load would have increased by an estimated 20,000 tons above the 70,000 tons computed from the original model. Comparable values of return flow salt load were obtained for the other years modeled.

Another model parameter which might be somewhat altered by the proposed project is the delay time associated with flow through the groundwater basin. Without the proposed project this time was determined to be about three and one-half months. Utilizing 1965 as an illustrative year, the effects of the delay time upon the outflow graphs of water and salt from the basin are shown in Figures I-1 and I-2 in Appendix I. The delay time effects only the temporal distribution of flows, but not the total flow quantity. For example, during the calendar year of 1965 the computer indicated that 35,000 tons more salt would bypass the basin outflow with a two month delay than with the three and one-half month time delay. Similarly, with a five month delay 32,000 tons less salt would leave the basin during 1965 than with the three and one-half month delay. Both cases are based on the initial conditions computed by the model at the end of 1964.

Another system variable which effects the mass rate of water and salt outflow is the available soil moisture storage capacity within the plant root zone. In general, for particular rates of irrigation the lower the available soil moisture storage capacity, the greater are the rates of deep percolation. This segment of return flow waters usually increases the salt load originating within the irrigated area and changes the timing at which the water and salts reach the basin outflow. Figure I-3 in Appendix I illustrates the effects of the soil moisture storage capacity on the water outflow from the system for 1965 with the proposed irrigation project. With a moisture capacity of only 3.0 inches, the water outflow from the system for 1965 was 40,000 acre-feet more than when the capacity was at 5.5 inches. When the soil moisture capacity is increased to 8.0 inches, the basin outflow is decreased by 15,000 acre-feet from the value obtained at the 5.5 inch capacity. The difference in outflow quantities is a reflection of the availability of water to the crops in the system for consumptive use. Differences are also produced because of the time required for the percolating flows to pass through the groundwater system. The effects of the soil moisture capacity on salt outflow are illustrated by Figure I-4. Again, when the moisture capacity is at 3.0 inches, the salt outflow from the basin is 35,000 tons more than when it is at the 5.5 inch level, and decreases by 28,000 tons when the soil moisture capacity is increased to 8.0 inches. These differences result partly from the changed water recharge rates to the groundwater system.

Crop distribution within the proposed project also influences water and salt outflow characteristics. If crops are grown which consume relatively less water, the decrease in water use and the increase in the salt load are reflected at the basin outlet, providing the diversions are maintained at the same rate. Under this alternative the added salt load is associated with a greater rate of water percolating into the groundwater system. Conversely, if crops are grown that transpire large quantities of water, outflows from the basin of both water and salt are decreased if all other factors, including diversion rates, remain constant. To illustrate, three different crop distributions were selected and substituted in place of the one initially proposed by the project. The first alternative distribution consisted of 50 percent alfalfa, and 25 percent each of grains and pasture. The computer model indicated that the annual consumptive depletion from the basin would be increased by approximately 18,000 acre-feet over the distribution initially proposed by the project. The average (1931-60) reduction in salt load from the agriculture system was computed to be about 13,000 tons annually. Corresponding results for 1965 indicated a 20,000 acre-feet increase in crop evapotranspiration and a decreased agricultural salt load of 17,000 tons from the estimated quantities under the crop distribution proposed by the project.

Two other alternative crop distributions were selected, not because of the feasibility of their utilization, but rather to indicate the possible magnitudes of evapotranspiration depletions. One distribution consisted entirely of alfalfa, which is considered to be a high water consuming crop. The other distribution was entirely grain crops, and, therefore, reflected the effects of low evapotranspiration rates in the basin. Under the alfalfa, the average annual increase in cropland consumptive use was computed to be 43,000 acre-feet. The agricultural salt load under these circumstances was reduced by 33,000 tons. Under the grain distribution, the average cropland evapotranspirational use was reduced by 32,000 acre-feet per year and the salt load increased by 47,000 tons per year. These values are somewhat biased because no change in the diversion requirement of the crops was considered. In actual practice, it is entirely possible that only the water outflow characteristics would change with the crop distribution pattern and not the salt discharge.

A further management alternative entertained is the addition of drainage works. Provision of adequate drainage through the entire basin would essentially eliminate the deep percolation of water into the groundwater system, which would in turn decrease the salt load from the agricultural system. The hydro-salinity model of the system was reprogrammed to consider the basin as being adequately drained in that no deep percolation occurred. The effects of this change resulted in no change to the hydrologic system on an annual basis and affected only the time distribution of flow on a monthly basis. However, the salt load from the irrigated area was decreased. In 1965, the annual decrease in salt outflow from the area amounted to 60,000 tons when compared with the estimated quantity for undrained conditions. The average (1931-60) decrease was computed to be 35,000 tons. Adequate drainage within the modeled area would appear to greatly reduce the salt load attributable to the agricultural system.

The final model parameter to be varied in this study was that of irrigation efficiency, which is defined (Equation 3.12) to be a composite of the conveyance and application efficiencies. In general, high irrigation efficiencies are associated with low application rates in terms of crop needs. Under these conditions a salt might not be maintained within the soil root zone of the agricultural land, and salt accumulation in the soil might occur. This situation would be reflected in the decreased salt tonnage monitored at the basin outlet.

High application rates usually maintain the stored soil moisture at or near capacity so that the actual rate of evapotranspiration equals the potential rate (Equation 3.26), and deep percolation rates are high. Irrigation practices which produce significant deep percolation flows might appreciably alter the outflow hydrograph from the basin. These flows are delayed as they move through the groundwater basin. In the computer model, for example, these flows may not be observed at the outflow gage until the first few months of the second model year because of the time delay from their diversion in the latter months of the first year. Furthermore, these flows of water usually accumulate a significant increase in salt load from the irrigated areas.

For a given rate of diversion for irrigation, an increase in the numerical value of the efficiency parameter produces a decrease in the rate of overland and interflow and an increase in the rate of infiltration into the soil, which in turn increases the deep percolation rates. Figures I-5 and I-6 in Appendix I illustrate effects as predicted by the model of low, average, and high irrigation efficiency values on outflows of water and salt from the proposed irrigation project during the year 1965. The low and high values of 10 and 90 percent, respectively, are presented only to emphasize the kinds of change in magnitude and temporal distribution of the flows which might result from changing the irrigation efficiency.

For 1965 the computed outflow of water from the proposed project was 2,465,000, 2,310,000, 2,250,000, 2,225,000, and 2,170,000 acre-feet for 10, 30, 45, 60, and 90 percent application and conveyance efficiencies, respectively. Under a constant diversion rate the 90 percent efficiency resulted in an increased water flow of approximately 65,000 acre-feet during the first few months of 1966. This effect was produced by the time delay in the return of the deep percolating flows to the basin outflow point. The average annual 1931-60 outflow from the basin was 1,620,000, 1,460,000, 1,365,000, 1,360,000, and 1,360,000 acre-feet for a 10, 30, 45, 60, and 90 percent conveyance and application efficiency, respectively.

The computed salt loads leaving the basin for the year 1965 were 900,000, 855,000, 910,000, 920,000, and 1,000,000 tons annually for 10, 30, 45, 60, and 90 percent efficiency values, respectively. The estimated annual salt discharge was higher for the 10 percent value than the 30 percent value because of the 25 percent increase in loading, which was assumed to apply to all overland and interflows returning from agricultural lands. Comparable average annual salt loads for the 1931-60 period would be 865,000, 780,000, 745,000, 835,000, and 925,000 tons for the same efficiency values, respectively. If no salt pickup by overland and interflows were assumed, the computed average annual salt discharge would be approximately 715,000 tons. This figure indicates an average salt accumulation rate within the soil profile of about 110,000 tons annually at efficiency values of 10 and 30 percent, since no leaching occurs in either case.

Depending upon the level of irrigation efficiency realized in the proposed irrigation project, it is apparent from the computer output that the average annual salt contribution from the project can vary from a deposition or loss of about 110,000 tons to an increase of 185,000 tons. These estimates are based on the assumption that the irrigation diversion rate remains constant. On the basis of these results, the agriculture system would contribute little more than 1.5 tons per acre per year.

Alternative diversion schemes

For the proposed irrigation project to be meaningful, the annual depletion to the San Juan River system should be confined to New Mexico's allocated share of Upper Colorado River basin water. It is estimated that New Mexico is entitled to consumptively use about 680,000 acre-feet per year. Of the total allocation, it is estimated on an annual basis that 88,500 acre-feet are presently committed to existing rights, and that about 92,000 acre-feet per year are required for New Mexico's share of the upper basin main stem reservoir losses. The water remaining for future development is equivalent to about 500,000 acre-feet per year. The proposed irrigation project would consumptively use an average of about 325,000 acre-feet annually leaving 175,000 acre-feet for other development.

A management alternative considered in this study was to eliminate the proposed irrigation project to satisfy all existing rights and estimated depletions within the area and to export the remaining water from the San Juan River basin using Navajo Reservoir as the point of origin. The average annual export flow was estimated to be about 500,000 acre-feet. Under a distribution pattern which called for 3.0 percent during January, February, March, November, and December; 6.0 percent in April and October; 14.5 percent in May and August; 17.0 percent in June and July; and 10.0 percent in September. Figure I-7 shows average annual water and salt outflow graphs based on the 1931-60 period both with and without the exportation of New Mexico's allocated share of Colorado River water. Without the export scheme the average annual water discharge from the subbasin was computed to be 1,665,000 acre-feet which carried a corresponding salt load of 825,000 tons. Under export conditions the average annual computed water discharge was reduced by 500,000 acre-feet, as expected, and the salt flow from the area was reduced by about 220,000 tons per year. The model indicated that the water export scheme would increase the average annual outflow salinity concentration by about 10 ppm. It appears that the most significant change in monthly dissolved solids concentration would occur in January for which an average increase of 310 ppm was predicted.

Based on the 1931-60 period, the average annual diversion to the proposed irrigation project was estimated to be about 750,000 acre-feet. Exportation of this quantity of water on an annual basis has little practical significance because it exceeds New Mexico's allotted share of water. However, for the sake of interest, a model study was performed for conditions which assumed that on an average annual basis this quantity of water was exported from the basin. As would be expected, the annual discharge from the basin was reduced by about 750,000 acre-feet, and the corresponding salt loads from the basin were reduced by 300,000 tons per year for the 1931-60 period, and 275,000 tons for the year 1965. This scheme, therefore, would increase the annual outflow salinity concentration levels by 40 ppm for 1931-60 period and about 15 ppm for year 1965. Basically, the increase in salinity concentration at the basin outflow occurs because of the relatively constant natural load which apparently occurs regardless of export quantities.

An alternative to export would be to consumptively use most diversions within the basin. Under this alternative it would be entirely possible for the salt load carried by the diverted waters to be returned to the river in a small fraction of the original diversion. Flow depletions from the annual basin outflow would be nearly equivalent to the amount of water diverted. However, the total salt flow from the basin would change little. For example, if the annual consumption were 500,000 acre-feet, the remaining portion of New Mexico's allocated share of Colorado River water, the average annual 1931-60 outflow of the San Juan River at Shiprock would be reduced by that amount to a value of 1,165,000 acre-feet. The average annual salt discharge for this period would be maintained at approximately the same level. If the water depletion occurred from a user which added no additional salt load, the salt load would average 825,000 tons per year for 1931-60 period and maintain an average annual salinity outflow concentration of about 520 ppm (an increase of about 150 ppm over present conditions). Alternatively, if the water depletion occurred from agricultural uses, the salt load would be increased by an additional load from the soil system.

In summary, this study has demonstrated the practical utility of a computer model for examining many possible alternatives in water resource planning and management.

CHAPTER IX

RECOMMENDED RESEARCH NEEDS FOR MODEL IMPROVEMENT

The scope of this research project has been macroscopic in nature. The gross hydro-salinity model marks many details of the complex processes which occur within the basin. Inadequate data frequently restrict the ability of a model to define a system. In this study, more complete data would enable refinement of significant processes within the computer program, and thus provide a model which more accurately simulates the hydro-salinity flow system.

A constant groundwater salinity concentration was assumed in the hydro-salinity model due to a lack of groundwater data. The concentration level was determined from measurements of the dissolved solids levels during surface stream base flow periods. Since these measurements reflect only a partial image of the real system, additional effort is needed to obtain groundwater quality data which accurately represents the real system. These data could be incorporated to refine and improve the definition of the model developed herein.

An empirical relationship resulting from the hypothesis of interchange is offered to explain the source and apparent degree of natural salt loading as discussed in Chapter IV. The empirical relationship related the pick-up of natural salts only to the surface flow rate. Certainly such factors as the underlying geologic formations, depth and width of river alluvium, slope of stream channel, rate of natural groundwater recharge, rate of groundwater movement, rate of surface streamflow, time of solution of salts, degree of interchange or mixing between surface and subsurface flows, plus many other factors are related to the solution of salts in the natural system. The interchange relationship proposed may not be completely correct but is logically correct in premise. Regardless, the concepts underlying natural salt loading in a river system require additional research and study to completely define the salinity flow system.

It is recommended that the salinity flow system be given a first priority in research effort. This would provide a better understanding of the possible degree of management of the salinity flow system. Additional research is needed within the agricultural system to relate the role of irrigation to increased salt loading. Factors such as irrigation practices, soil types, leaching of salts, ion exchange within the soil complex, physical improvement of farms, efficiency of water use, and other parameters related to the irrigation system, all require additional investigation to provide the proper perspective of the role of agriculture in the salinity flow system.

Somewhat related to the agricultural contributions to the salinity flow system are the effects of salinity on crop production and farm yields. Application of a highly saline water to agriculture crops reduces the crop yield. It would appear that effort should be expended to more fully determine the economic loss associated with the use of water with a high total dissolved solids concentration.

Another area worthy of investigation is the routing of salts, both collectively and individually, through a reservoir system. The model would require consideration of salt deposition, stratification, and solution from the confining boundary. The possibility of utilizing the reservoir for salinity control purposes could be investigated, as well as the assets and disadvantages of a more uniform outflow salinity level compared to the highly variable salinity inflow concentration.

This simulation effort also indicated the need for additional study and development of relationships necessary to predict the probable salt load and TDS concentration of water originating from thundershower activity that is common to much of the basin. Factors such as storm location, precipitation intensity, vegetative cover, surface exposure, and time of contact all effect the potential solution rate of "flushing" of salts that are transported downstream by the storm water. This study assumed a constant average salinity concentration associated with surface runoff because of data limitations which precluded adequate simulation of the flushing process.

Related to the salt load originating from thundershowers is the necessary technique to adequately estimate the chemical composition and TDS concentration of water which originates on watersheds with water quality data deficiencies. Some of the required variables that are necessary to predict the quality of such water include discharge rate, time, vegetative cover, evapotranspiration, flow path or course, slope of the watershed, and geologic parameters. Once predictive methods are developed, they could be used in a vast portion of the Upper Colorado River basin which is lacking in adequate water quality data.

Preceding page blank

CHAPTER X
SUMMARY AND CONCLUSIONS

With the rapid growth of demands upon available water resources, optimum use considerations are playing an increasingly important role in water resource planning and development. In every hydrologic system each upstream use has some effect on the quantity, quality, and timing of flow occurring at downstream points. However, the problem of quantitatively assessing these downstream effects is a difficult one. The complex interrelation and variable nature of the many different processes and phenomena occurring simultaneously make this so. In other words, the extent of downstream effects, such as those caused by increased diversions at a specific location, depends upon the dynamic characteristics of the hydrologic system and the prevailing water use patterns within the basin.

Many of the factors which affect a water resource flow system are subject to management or regulation. In order to achieve optimum or feasible use patterns within limits imposed by particular constraints there is a definite need to assess management alternatives and to seek logical criteria for regulation and administration of water resources. Consequently, as pressures upon river basin resources increase, more sophisticated mechanisms are required for planning and management purposes. The advent of modern, high-speed, electronic computers has made possible the application of simulation techniques to complex systems of this nature.

In this report, a general model of the hydrologic and salinity flow systems is proposed and is synthesized on an analog computer. The basis of the model is a fundamental and logical mathematical representation of the various hydrologic and salinity flow processes. Spatial definition is achieved by dividing the modeled area into specific space increments, or subbasins, for which average values of space variable model parameters are applied. Temporal resolution is obtained by selecting a specific time increment over which average values of time varying parameters are used. The ultimate in modeling would utilize continuous time and space definition. However, the practical limitations of this approach are obvious. The complexity of a model designed to represent a hydrologic system largely depends upon the magnitude of the time and spatial increments used in the model. In model development it is, therefore, necessary to select increments which are consistent with time, budget, and computer capability constraints, and at the same time provide sufficient resolution to consider the kinds of questions which might be asked of the model.

Computer simulation of water resource systems has many practical applications in the areas of both research and project planning and management. As a research tool the computer is valuable in the process of investigating and improving mathematical relationships. In this respect, the computer is applied not only for its calculating potential, but also for its ability to yield optimum solutions. Simulation is also ideal for investigations of system sensitivity. Problems range from the influence of a single factor upon a particular process to the effects of an entire process, such as evapotranspiration, upon the system as a whole.

In many ways computer simulation can assist in planning and development work. For example, models can provide the designer with runoff estimates from the input of recorded precipitation data. In addition, simulated streamflow records from statistically generated input information enable the establishment of synthetic flow frequency distribution patterns.

In the area of water resource management, computer simulation permits the rapid evaluation of the effects of various management alternatives upon the entire system. These alternatives might involve such variables as watershed treatment, including urbanization, the construction of storage reservoirs, and changes in irrigation practices within a basin.

In the model of this study both the hydrologic and the salinity systems are simulated by tracing the mass rate of water and salt through various paths in a hydrologic unit. The salinity concentration associated with a given segment of water flow determines the volume of salts being transported by that particular segment. Hence, the salinity flow system is superimposed upon the hydrologic system and the two systems are linked by means of the salinity concentrations within the water. Both flow systems are greatly altered by the manage-

Preceding page blank

ment practices of man and interaction with various geologic formations.

In this study the computer model was applied to the hydrologic and salinity systems of the Upper Colorado River basin. To provide spatial resolution the basin was divided into 40 subareas or subbasins, and each was modeled separately. The submodels then were linked into a single model of the entire basin. In general, subbasin boundaries were established on the basis of the availability of water salinity data. Only the valley floors were included within the modeled area with both gaged and ungaged tributary inflows of water and salt from the surrounding drainage areas being represented by either observed or estimated input quantities. The time increment selected for the model was one month, and time varying quantities therefore were expressed in terms of mean monthly values.

The only water quality parameter considered in the model development was total dissolved solids (TDS) or salinity. In general, this parameter has been most responsible for limiting water reuse in the irrigated and sparsely settled areas of the western United States. Unmeasured water input quantities are estimated through correlations based on precipitation, snowmelt, and gaged streamflow rates. Salt flow rates are estimated by associating a salinity concentration with each water flow component. It is assumed that no salts are carried by precipitation quantities. Input flows are routed, delayed, increased, or abstracted by means of diversions, return flows, municipal and industrial depletions, evapotranspiration, and salt loading from natural sources. The evapotranspiration rate is estimated from an empirical relationship that is dependent upon surface air temperature, latitude, available soil moisture, and crop species. No abstractions from the salinity flow system occur through the evapotranspiration process. The rate of natural salt pick-up is determined from an empirical relationship based on the degree of interchange between surface and subsurface flows within the basin. In addition, an annual salt balance within the agricultural system was assumed. The water and salts which flow through the system are changed both spatially and as water with its accompanying salt load moves through a hydrologic system, storage changes and abstractions occur. The resulting response or output functions represent the integrated effects of the many physical and chemical processes which occur within the system.

The mathematical expressions which were used to describe the various system relationships were synthesized into a program for the electronic analog computer. These expressions contain certain coefficients or model parameters which are evaluated and fixed during the model calibration procedure. Under this procedure data for a given subbasin are input to the computer, and the model coefficients are then adjusted until observed and computed output functions closely match. In this study the model was calibrated for each subbasin by matching observed and computed output functions for water and salt over a period of 24 consecutive months. So far as possible the calibration period was selected to represent a wide range of flow conditions.

A detailed description is given of the modeling procedure for the White River subbasin. In addition, the report sets out a brief description of the main characteristics of each of the remaining 39 subbasins. The model coefficients or parameters which were established for each subbasin through the calibration procedure are given by Appendix H.

Schematic diagrams setting out estimated average annual flow quantities by subbasin for both water and salt are shown by Figures 7.1, 7.2, and 7.3. These estimates are based on the 1931-60 period and reflect cropping and river flow regulation conditions as of 1960. These diagrams indicate an average annual crop consumptive use rate of 2,650,000 acre-feet within the Upper Colorado River basin and a virgin water flow at Lee Ferry of about 14 million acre-feet per year. The estimated salt flow at Lee Ferry is 8.6 million tons per year of which approximately 4.3 million tons originate from natural sources, 1.5 million tons from within the agricultural system, and 2.8 million tons from other inputs to the system. The salt load originating from within the agricultural system and cropland consumptive use increase the total dissolved solids concentration within the Upper basin by 104 and 113 ppm, respectively. The average salinity level of water leaving the basin at the present time is 579 ppm.

The utility of the model for predicting the effects of various possible water resource management alternatives is demonstrated for a proposed irrigation development in northwest New Mexico, which would bring 110,600 acres of irrigable land into production. The effects of the proposed project as predicted by the model are illustrated by computer output plots.

Because of its fast turn-around and graphical display capabilities and its ability to solve differential equations, the analog computer is very efficient for model development and verification. However, for operational studies many models, once verified, can be readily programmed for solution on the more common all-digital computer.

In conclusion, it is again emphasized that a model is limited by the availability of the field data used in the verification process. As further data become available, the model can be improved in terms of both the accuracy with which it defines individual processes and its time and spatial resolution. Modeling is, therefore, a continuous process, with each phase providing further insight and understanding of the system, and thus leading towards additional refinement and improvement of the model.

For each simulation study certain constraints or boundary conditions limit the degree of achievement during any particular phase of the overall program. The most important of these limiting features are the extent to which research information and basic input data are available, the degree of accuracy established by the time and spatial increments adopted for the model, equipment limitations, and the necessary time limit imposed upon the investigation period.

The model presented by this report represents a particular phase in the development of a simulation model of the hydrologic and salinity flow systems of the Upper Colorado River basin. Further development of the model will continue, and other related dimensions, such as economics, eventually will be added. Improved definition of the salinity flow system, particularly the interchange phenomenon, is needed. However, the model is now capable of answering many questions pertaining to the management of the water resources of the basin. The study has demonstrated the soundness and validity of the computer simulation approach to hydrologic problems within the Upper Colorado River basin, and has provided a firm basis for extending the model to include additional dimensions encountered in the comprehensive planning and management of water resource systems.

BLANK PAGE

SELECTED REFERENCES

Anderson, T. W. 1968. Electrical-analog analysis of the hydrologic system in Tucson, Arizona. Publication No. 80, International Association of Scientific Hydrology, University of Arizona, Tucson, Arizona. December.

Bagley, Jay M., Robert B. Hickok, D. G. Chadwick, Marvin J. Rosa, and D. L. Brakensiek. 1963. Report on feasibility of an electronic analog approach to Sevier River basin investigations for water resources development and conservation planning. Report No. EC-51-g-1, Engineering Experiment Station, Utah State University, Logan, Utah. 47 p.

Betson, R. P., and R. F. Green. 1968. Analytically derived unit graph and runoff. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 94(HY6): 1489-1505.

Bishop, A. Alvin, and Howard B. Peterson. 1969. The characteristics and pollution problems of irrigation return flow. Contract No. 14-12-408, with Federal Water Pollution Control Administration, U.S. Department of Interior. May. 265 p.

Blaney, Harry F., and Wayne D. Criddle. 1950. Determining water requirements in irrigated areas from climatological and irrigation data. Technical Paper 96, Soil Conservation Service, U.S. Department of Agriculture. February. 48 p.

Chow, Ven Te. 1964. Handbook of applied hydrology. McGraw-Hill Book Company, Inc., New York. 1453 p.

Christiansen, J. E. 1966. Estimating pan evaporation and evapotranspiration from climatic data. Proceedings of the Symposium on Methods for Estimating Evapotranspiration, ASCE Irrigation and Drainage Conference, Las Vegas, Nevada. November 2-4. pp. 193-234.

Christiansen, J. E. 1968. Estimating pan evaporation and evapotranspiration from climatic data. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 94(IR2):243-265. June.

Cohen, J. B., and R. L. O'Connell. 1963. The analog computer as an aid to stream self-purification computations. Journal of the Water Pollution Control Federation 35(8):951-962.

Connor, J. G., and C. G. Mitchell. 1958. A compilation of chemical quality data for ground and surface waters in Utah. Technical Publication No. 10, State Engineers Office and U.S. Geological Survey, Salt Lake City, Utah.

Crawford, N. H., and R. K. Linsley. 1962a. The synthesis of continuous streamflow hydrographs on a digital computer. Department of Civil Engineering, Technical Report No. 12, Stanford University, Stanford, California.

Crawford, N. H., and R. K. Linsley. 1962b. Digital simulation in hydrology. Stanford Watershed Model IV. Department of Civil Engineering, Technical Report No. 39, Stanford University, Stanford, California.

Dawdy, D. R., and T. O'Donnel. 1965. Mathematical models of catchments behavior. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 91(HY4):123-139.

Division of Water Resources of Utah. 1968. Land use surveys for Duchesne River and Ashley Creek Basins. Unpublished report. State Capital Building, Salt Lake City, Utah.

Dixon, Neal P., David W. Hendricks, A. Leon Huber, and Jay M. Bagley. 1970. Developing a hydro-quality simulation model. PRWG67-1, Utah Water Research Laboratory, Utah State University, Logan, Utah. June.

Doneen, L. D. 1959. Evaluating the quality of irrigation waters. Bulletin No. 75, State Department of Water Resources, Sacramento, California. pp. 1-33.

Falk, Lloyd L. 1962. Analog computer–a modern tool in water pollution control. Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers 88(SA6):31-59.

Gardner, W. R., and C. F. Ehlig. 1963. The influence of soil water on transpiration by plants. Journal of Geophysical Research 68(20):5719- 5724.

Grassi, Carlos Julian. 1964. Estimation of evapotranspiration from climatic formulas. M.S. Thesis, College of Engineering, Utah State University, Logan, Utah. 101 p.

Harder, J. A., Lyle Mockros, and Ray Nishizaki. 1960. Flood control analog. Water Resources Center Contribution No. 24, Hydraulic Laboratory, University of California. 40 p.

Hem, John D. 1959. Study and interpretation of the chemical characteristics of natural waters. Water-Supply Paper No. 1473, U.S. Geological Survey. 269 p.

Preceding page blank

Hendrickson, A. H., and F. J. Veihmeyer. 1937. Responses of fruit trees to comparatively large amounts of available moisture. Proceedings of the American Society Horticulture Science 35:289- 292.

Hopkins, C. D., Jr., and D. O. Hackett. 1961. Average antecedent temperatures as a factor in predicting runoff from storm rainfall. Journal of the Geophysical Research 66(10):3313-3318.

Hyatt, M. Leon, J. Paul Riley, and Eugene K. Israelsen. 1968. Utilization of the analog computer for simulating the salinity flow system of the Upper Colorado River Basin. Publication No. 80, International Association of Scientific Hydrology. University of Arizona, Tucson, Arizona. December.

Iorns, W. V., C. H. Hembree, D. A. Phoenix, and G. L. Oakland. 1964. Water resources of the Upper Colorado River basin--basic data. Professional Paper 442, U.S. Geological Survey.

Iorns, W. V., C. H. Hembree, and G. L. Oakland. 1965. Water resources of the Upper Colorado River basin–technical report. Professional Paper 441, U.S. Geological Survey.

Israelsen, Eugene K., and J. Paul Riley. 1968. Application of an electric analog computer to a study of water resources management. Publication No. 80, International Association of Scientific Hydrology, University of Arizona, Tucson, Arizona. December.

Israelsen, Orson W., and Vaughn E. Hansen. 1967. Irrigation principles and practices. John Wiley and Sons, Inc., New York. 447 p.

Jey, C. H. 1960. Stream depletion of the San Juan River basin in Colorado. Colorado Water Conservation Board, Denver, Colorado. March.

Kalinin, G. P. 1968. Main trends in utilization of electronic computers in hydrologic investigations in USSR. Publication No. 81, International Association of Scientific Hydrology, University of Arizona, Tucson, Arizona. December.

Kohler, M. A., and R. K. Linsley, Jr. 1951. Predicting the runoff from storm rainfall. U.S. Weather Bureau Research Paper No. 34.

Linsley, Ray K., Jr., Max A. Kohler, and Joseph L. H. Paulhus. 1958. Hydrology for engineers. McGraw-Hill Book Company, Inc., New York. 340 p.

Lowry, R. L., and A. F. Johnson. 1942. Consumptive use of water for agriculture. Transactions of the American Society of Engineers 107:1243-1302.

Machmeier, R. E., and C. L. Larson. 1968. Runoff hydrographs for mathematical watershed model. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 94(HY6): 1453-1474.

Moore, D. O. 1968. Synthesizing daily discharge from rainfall records. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 94(HY4):1283-1298.

McCullock, Allan W., Jack Keller, Roger M. Sherman, and Robert C. Mueller. 1967. Ames Irrigation Handbook, W. R. Ames Company, Milpitas, California.

Odum, Howard T. 1960. Ecological potential and analogue circuits for the ecosystem. American Scientist 48(1):1-8.

Otoba, Kotaro, Kozi Shibantani, and Hiroshi Kewata. 1965. Flood simulator for the River Kitakami. Simulation 4(2):86-98. February.

Packer, M. R., J. Paul Riley, and Eugene K. Israelsen. 1968. Simulation of the hydrologic-economic flow system. Publication No. 81, International Association of Scientific Hydrology, University of Arizona, Tucson, Arizona. December.

Patel, Bal. B. 1962. A new formula for the evaluation of evaporation. M.S. Thesis, College of Engineering, Utah State University, Logan, Utah. 87 p.

Penman, H. L. 1948. Natural evaporation from open water, bare soil, and grass. Proceedings of the Royal Society of London, Series A. 193:120-146.

Phelan, John T. 1962. Estimating monthly "k" values for the Blaney-Criddle formula. Presented at the Agriculture Research Service--Soil Conservation Service Workshop on Consumptive Use, Phoenix, Arizona. March 6-8. 11 p.

Rennerfelt, J. G. W. 1964. An analog computer for oxygen sag calculations. Advances in water pollution research. Proceedings of the International Conference held in London, September 1962. The Macmillan Company, New York. pp. 79-87.

Richards, L. A. (editor). 1954. Diagnosis and improvement of saline and alkali soils. Agriculture Handbook No. 60, U.S. Department of Agriculture. February.

Riley, J. Paul, D. G. Chadwick, and J. M. Bagley. 1966. Application of electronic analog computer to solution of hydrologic and river-basin planning problems: Utah simulation model II. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Riley, J. Paul, J. M. Bagley, D. G. Chadwick, and E. K. Israelsen. 1967. The development of an electronic analog device for hydrologic investigations and conservation planning in the Sevier River Basin: Utah Simulation Model I. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Riley, J. Paul, and D. G. Chadwick. 1967. Application of an electronic analog computer to the problems of river basin hydrology. Utah Water Research Laboratory, Utah State University, Logan, Utah. December.

Riley, J. Paul, V. V. Dhruva Narayana, and Kousoum S. Sakhan. 1969. Electronic analog computer simulation of the Paez-Pedraza Region of Venezuela. Report PR-WG 64-1, Utah Water Research Laboratory, Utah State University, Logan, Utah. February.

Robinson, T. W. 1968. The real extent of phreatophytes and hydrophytes in western states. Unpublished report. U.S. Geological Survey. Menlo Park, California.

Schicht, Richard J. 1963. An electric analog model study of a sand and gravel aquifer in the East St. Louis area, Illinois. Presented at the 1963 Winter Meeting, American Society of Agricultural Engineers, Chicago, Illinois, December 1963. Paper No. 63-739. 28 p. (Multi.)

Scofield, Carl S. 1940. Salt balance in irrigated areas. Agricultural Research 61:17-39.

Shen, John. 1965. Use of analog models in the analysis of flood runoff. Professional Paper 506-A, U. S. Geological Survey. 24 p.

Skibitzke, H. E. 1960. Electronic computers as an aid to the analysis of hydrologic problems. LASH Commission of Subterranean Waters, Publication No. 52, pp. 347-358.

Smith, R. J., and Associates. 1965. Water resources inventory for water division Number 4. State of Wyoming, Office Wyoming State Engineer.

Soil Conservation Service. Department of Agriculture. 1964. Irrigation water requirements. Technical Release No. 21, Washington, D.C. April. 61 p.

Stallman, Robert W. 1963. Calculation of resistance and error in an electric analog of steady flow through non-homogeneous aquifers. Water-Supply Paper 1544-G, U.S. Geological Survey. 20 p.

Thaine, J. P., L. Wilson, T. B. Hutchings, and J. Swenson. 1967. Chemical and physical properties of soils in the Carbon-Emery area, Utah. Utah Agricultural Experiment Station, Utah State University, Logan, Utah. September.

Thornthwaite, C. W., and J. R. Mather. 1955. The water balance. Drexel Institute Technical Publication in Climatology 8(1):1-104.

Thorne, D. W., and H. B. Peterson. 1954. Irrigated soils. McGraw-Hill Book Company, Inc., New York. 392 p.

U.S. Army. Corps of Engineers. 1956. Snow hydrology; summary report of snow investigations. North Pacific Division, Portland, Oregon. 437 p.

U.S. Army. Corps of Engineers. 1960. Runoff from snowmelt. Engineering and Design Manual 1110-2-1406. 75 p.

U.S. Bureau of Reclamation. Department of the Interior. 1966. Reevaluation report of Navajo Indian irrigation project in New Mexico. Summary and appendices. Denver, Colorado. July.

U.S. Bureau of Reclamation. Department of Interior. 1967. Quality of water of Colorado River Basin. Progress Report No. 3, Salt Lake City, Utah. January. 80 p.

U.S. Bureau of Reclamation. 1968. Irrigable lands in Upper Colorado River Basin. Unpublished preliminary tables. Salt Lake City, Utah.

U.S. Department of Agriculture. Soil Conservation Service. 1955. Soil survey, Grand Junction area, Colorado. Series 1940, No. 19. November.

U.S. Department of Agriculture. Soil Conservation Service. 1959. Soil survey, Roosevelt, Duchesne area, Utah. Series 1940, No. 24. December.

U.S. Department of Agriculture. Soil Conservation Service. 1962. Soil survey, San Juan area, Utah. Series 1945, No. 3. August.

U.S. Department of Agiculture. Soil Conservation Service. 1962. Water and related land resources, Gunnison River Basin in Colorado. Duplicated report.

U.S. Department of Agriculture. Soil Conservation Service. 1965. Water and related land resources. Colorado River Basin in Colorado. Duplicated report.

U.S. Department of Agriculture. Soil Conservation Services. 1966. Water and related land resources, White River Basin in Colorado. Duplicated report.

U.S. Department of Agriculture. Soil Conservation Service. 1967. Soil survey, Delta-Montrose area, Colorado. July.

U.S. Federal Water Pollution Control Administration. Department of the Interior. 1968. A digital computer output of unpublished water quality data for waters of the Upper Colorado River Basin. Unpublished report. Denver, Colorado.

U.S. Federal Water Pollution Control Administration. Department of the Interior. 1969. The mineral quality problem of the Colorado River Basin. Colorado River Basin Water Quality Control Project, Denver, Colorado. March.

U.S. Geological Survey. Department of the Interior. 1954. Compilation of records of surface waters of the United States through September 1950, Part 9, Colorado River basin. U.S. Geological Survey, Water-Supply Paper 1313.

U.S. Geological Survey. Department of the Interior. 1956-63. Quality of surface waters of the United States, Part 9, Colorado River basin. U.S. Geological Survey, Water-Supply Papers 1453, 1523, 1574, 1645, 1885, 1945, 1951.

U.S. Geological Survey. Department of Interior. 1961-67. Water resources data for Colorado, New Mexico, Utah, and Wyoming, Part 1, surface water records. Denver, Colorado, Santa Fe, New Mexico, Salt Lake City, Utah, and Cheyenne, Wyoming. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. Department of the Interior. 1964. Compilation of records of surface waters of the United States through September 1960, Part 9, Colorado River basin. U.S. Geological Survey, Water-Supply Paper 1733.

U.S. Geological Survey. Department of Interior. 1964-67. Water resources data for Colorado, New Mexico, Utah, and Wyoming, Part 2, water quality records. Denver, Colorado, Santa Fe, New Mexico, Salt Lake City, Utah, and Cheyenne, Wyoming. U.S. Government Printing Office, Washington, D.C.

U.S. Weather Bureau. 1950-66. U.S. Climatological Data, Supplement for 1951-1960 and Annual Summaries for Arizona, Colorado, New Mexico, Utah, and Wyoming. Volumes 63-75.

U.S. Weather Bureau. 1963. Three charts showing normal precipitation for the States of Utah and Colorado for the three periods: October to April, May to September, and full year, based upon the period of record 1931 to 1960. Office of the Utah State Engineer, Utah Water and Power Board, and the Soil Conservation Service, Salt Lake City, Utah.

Wadleigh, C. H., and A. D. Ayres. 1945. Growth and biochemical composition of bean plants as conditioned by soil moisture tensions and salt concentration. Plant Physiology 20:106-132.

Walton, William C., and Thomas A. Prickett. 1963. Hydrogeologic electric analog computers. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 89(HY6): 67-91.

West, A. J. 1959. Snow evaporation and condensation. Proceedings of the Western Snow Conference, Cheyenne, Wyoming. pp. 66-74.

Willardson, Lyman S., and Wendall L. Pope. 1963. Separation of evapotranspiration and deep percolation. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 89(IR3):77-88.

Wilson, L., T. B. Hutchings, and P. Shafer. 1968. Able land resources of Utah. Utah Agricultural Experiment Station, Utah State University, Logan, Utah. February.

APPENDIX A

Map of Each Subbasin, Location of Hydro-salinity Inputs, and Agricultural Land Location

BLANK PAGE

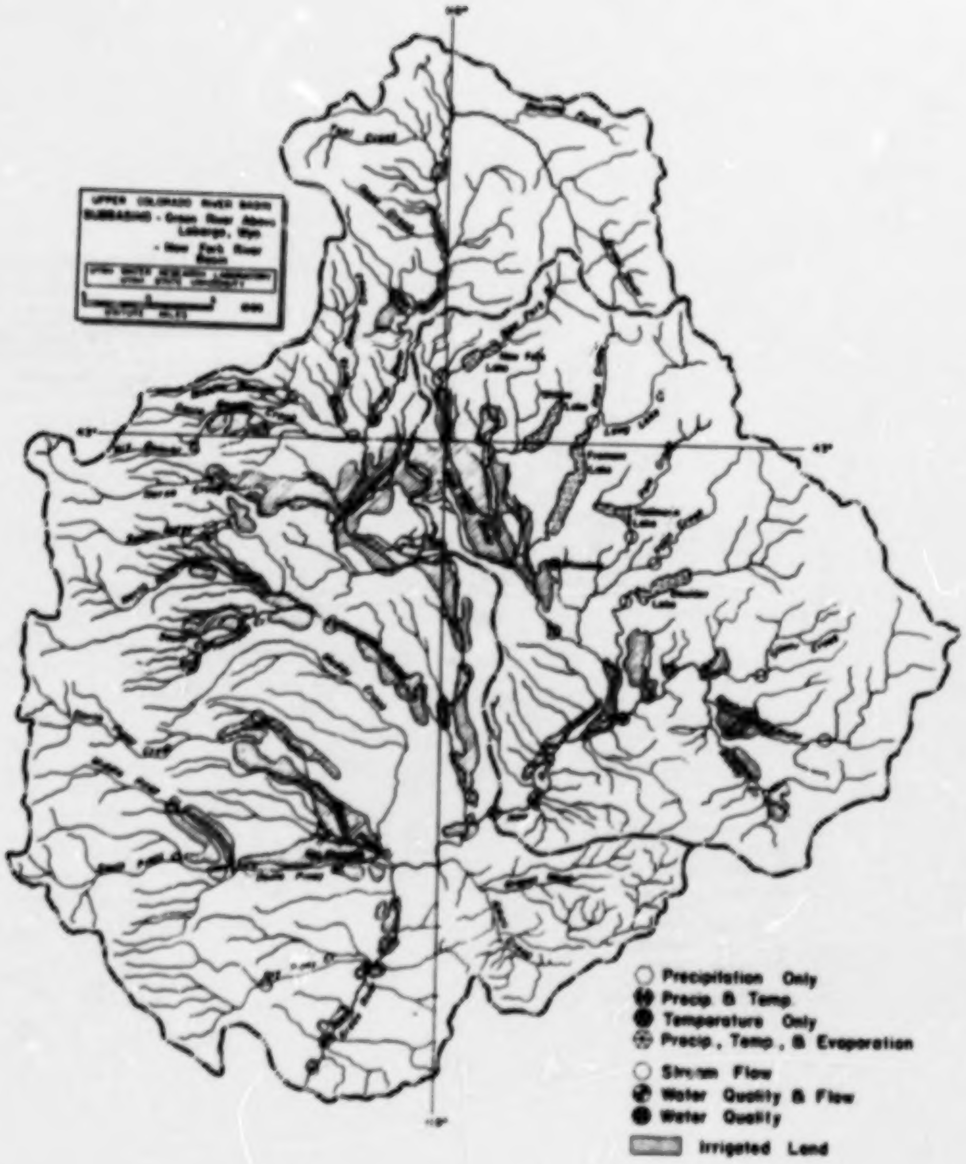

UPPER COLORADO RIVER BASIN
SUBBASINS - Green River Above LaBarge, Wyo
- New Fork River Basin
Precipitation Only
Precip & Temp
Temperature Only
Precip., Temp., & Evaporation
Stream Flow
Water Quality & Flow
Water Quality
Irrigated Land

Figure A1. New Fork River basin and Green River above LaBarge, Wyoming, hydrologic and salinity subbasins.

Preceding page blank

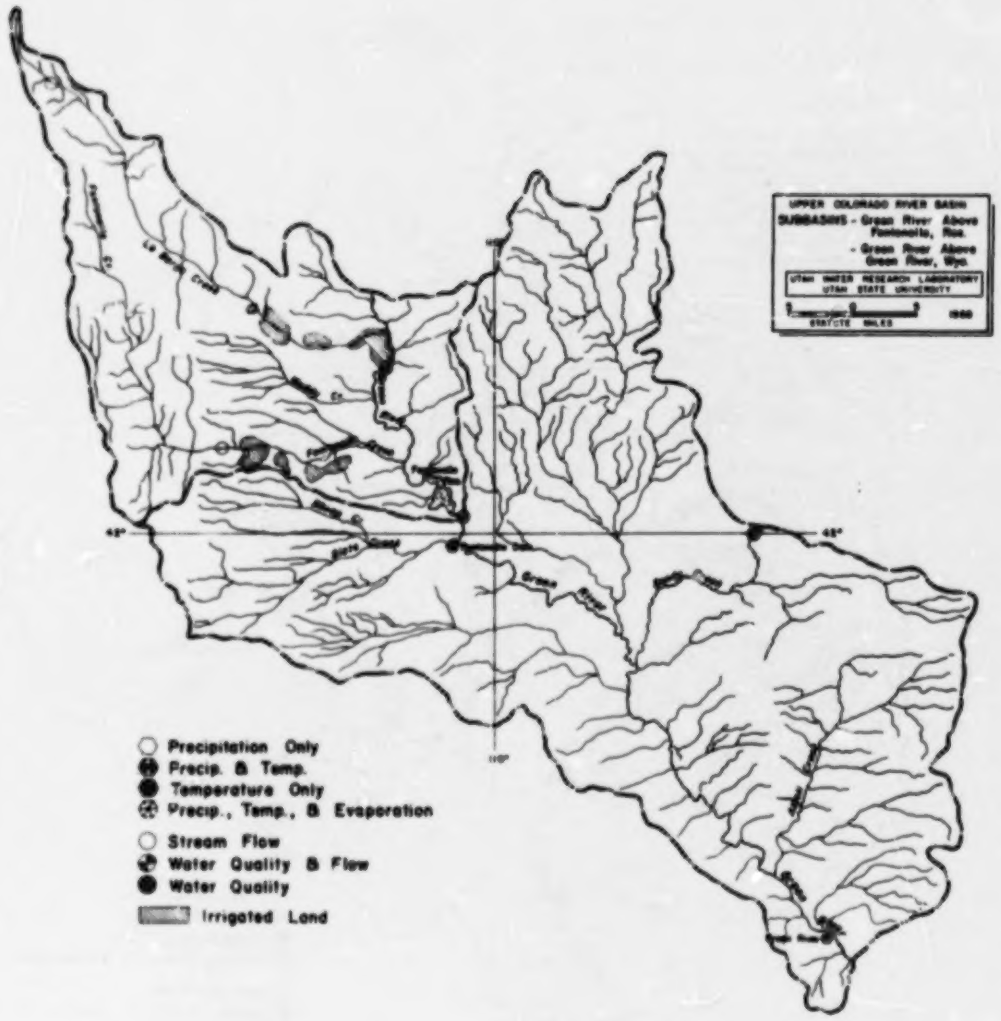

UPPER COLORADO RIVER BASIN
SUBBASINS - Green River Above Fontenelle, Res.
- Green River Above Green River, Wyo.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1980
42°
110°
Green River
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊕ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A2. Green River above Fontenelle Reservoir and Green River above Green River, Wyoming, hydrologic and salinity subbasins.

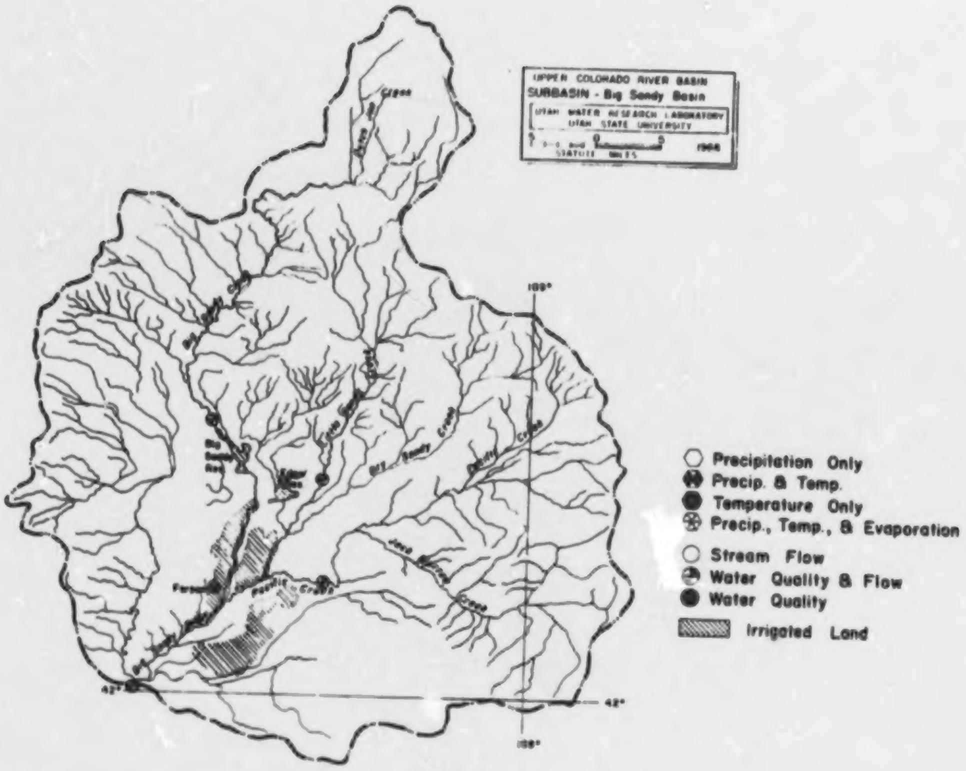

UPPER COLORADO RIVER BASIN
SUBBASIN - Big Sandy Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
0
5
STATUTE MILES
1968
109°
108°
42°
42°
○ Precipitation Only
Precip. & Temp.
● Temperature Only
Precip., Temp., & Evaporation
○ Stream Flow
Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A3. Big Sandy Creek basin, hydrologic and salinity subbasin.

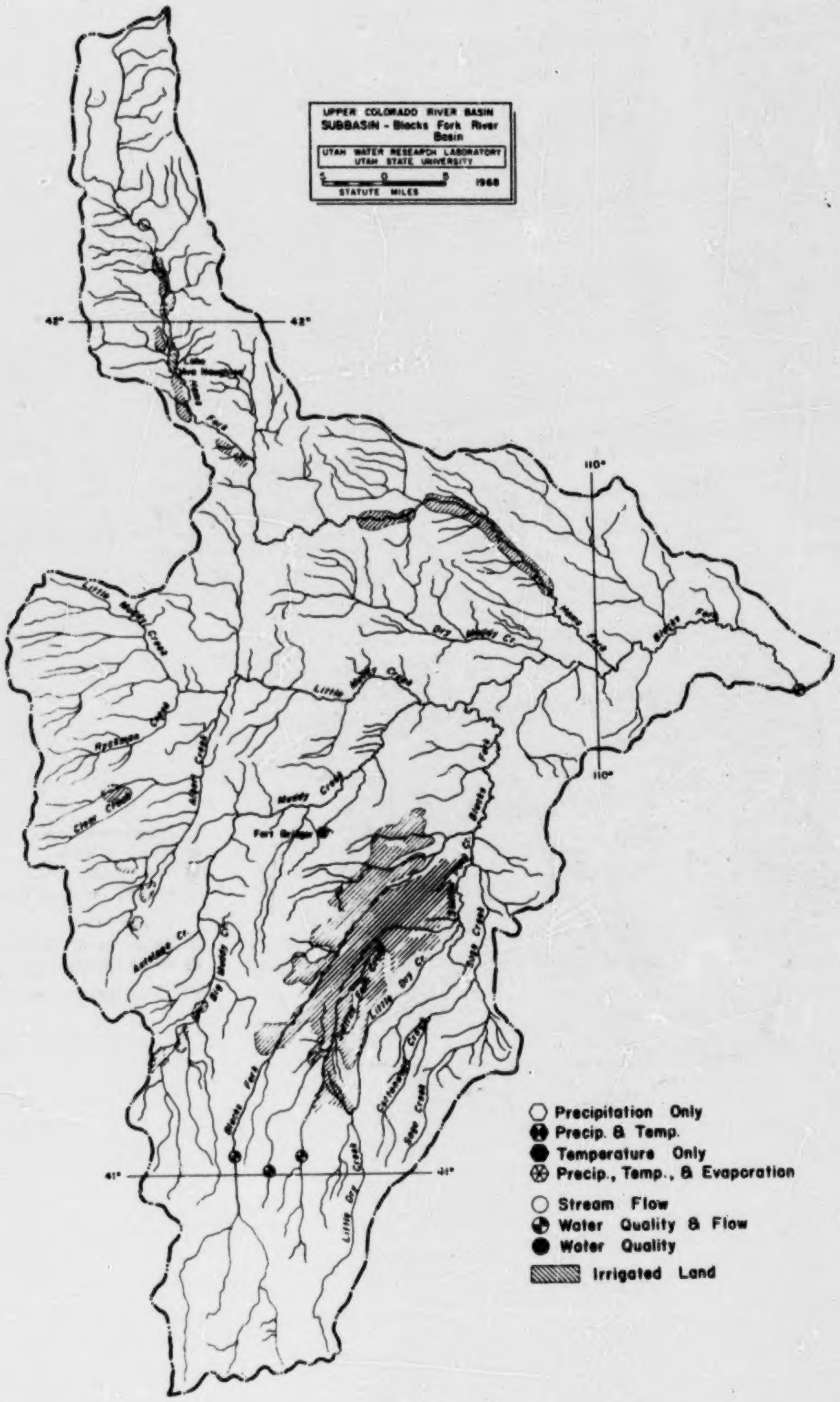

UPPER COLORADO RIVER BASIN
SUBBASIN - Blacks Fork River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
42°
42°
110°
110°
41°
41°
Little Muddy Creek
Dry Muddy Cr.
Hams Fork
Blacks Fork
Little Muddy Creek
Ryckman Creek
Albert Creek
Clear Creek
Muddy Creek
Fort Bridger
Blacks Fork
Antelope Cr.
Big Muddy Cr.
Smiths Fork
Little Dry Cr.
Cottonwood Creek
Sage Creek
Little Dry Creek
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A4. Blacks Fork River basin, hydrologic and salinity subbasin.

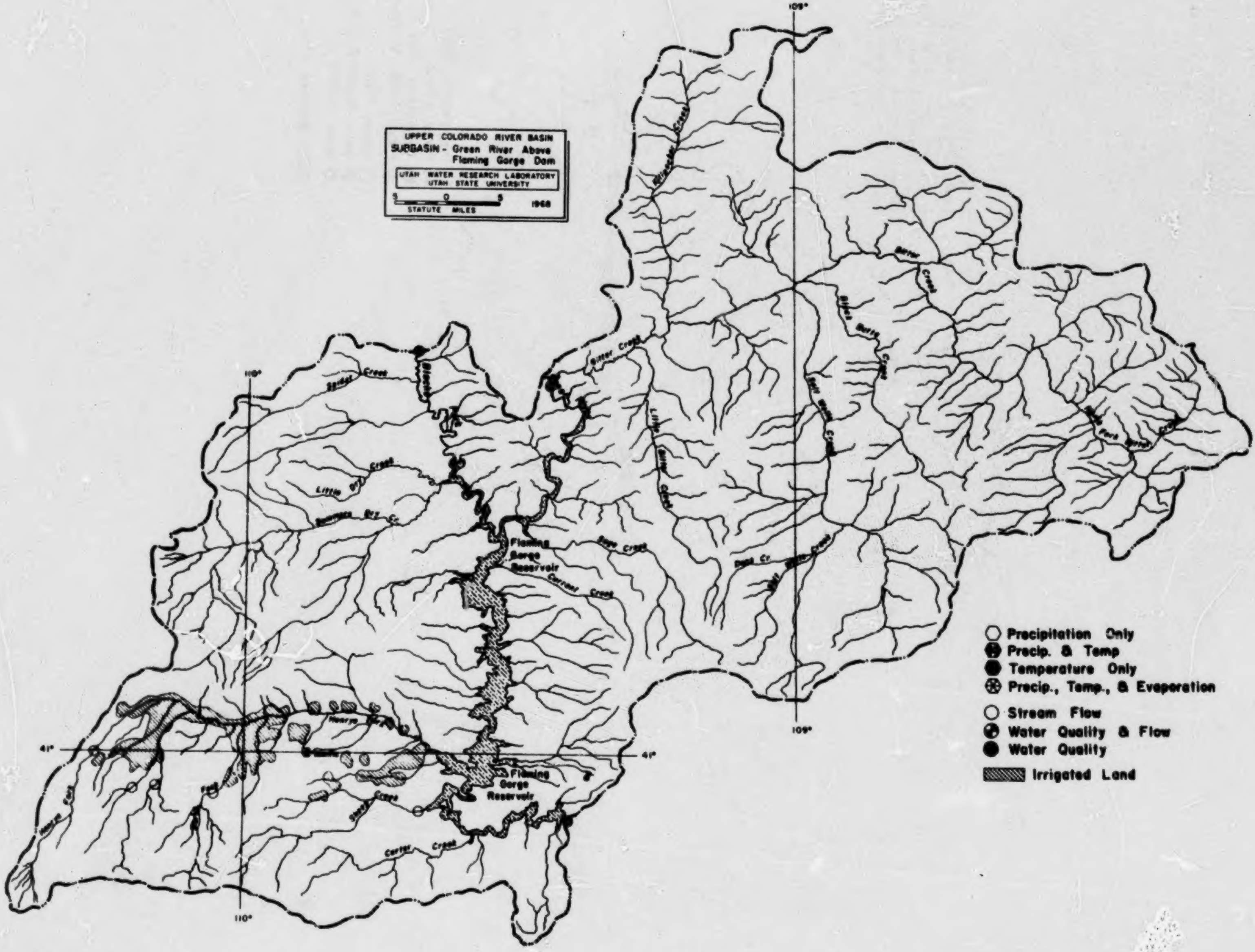

UPPER COLORADO RIVER BASIN
SUBBASIN - Green River Above Flaming Gorge Dam
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
109°
110°
41°
Bitter Creek
Little Bitter Creek
Salt Wells Creek
Black Butte Creek
Bitter Creek
North Fork Bitter Creek
Sage Creek
Dans Cr.
Flaming Gorge Reservoir
Current Creek
Spider Creek
Blacks
Little Dry Creek
Dry Cr.
Henrys Fork
Carter Creek
Flaming Gorge Reservoir
○ Precipitation Only
● Precip. & Temp
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A5. Green River above Flaming Gorge Dam, hydrologic and salinity subbasin.

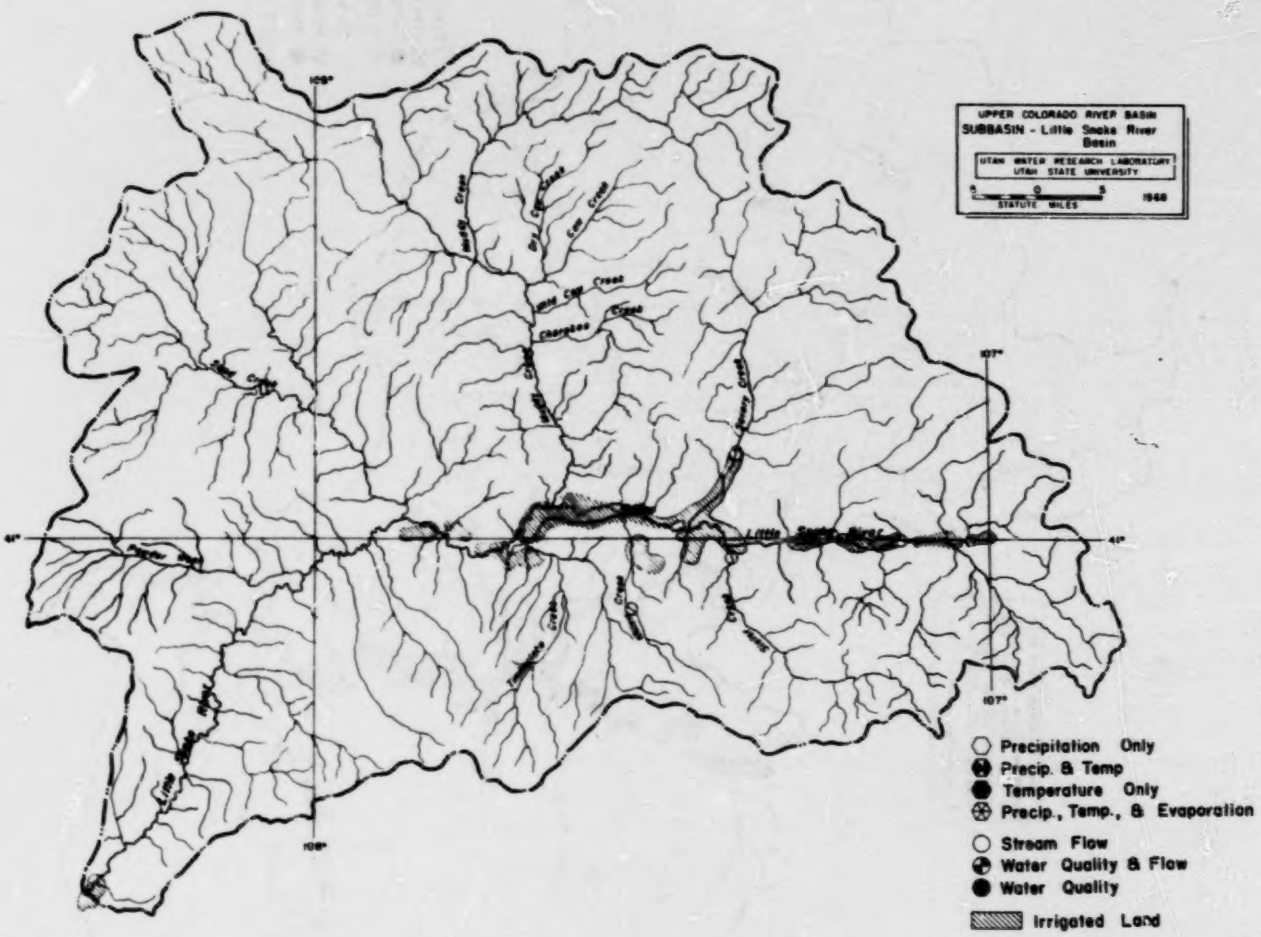

UPPER COLORADO RIVER BASIN
SUBBASIN - Little Snake River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
108°
107°
41°
Cow Creek
Little Cow Creek
Little Snake River
○ Precipitation Only
● Precip. & Temp
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A6. Little Snake River basin, hydrologic and salinity subbasin.

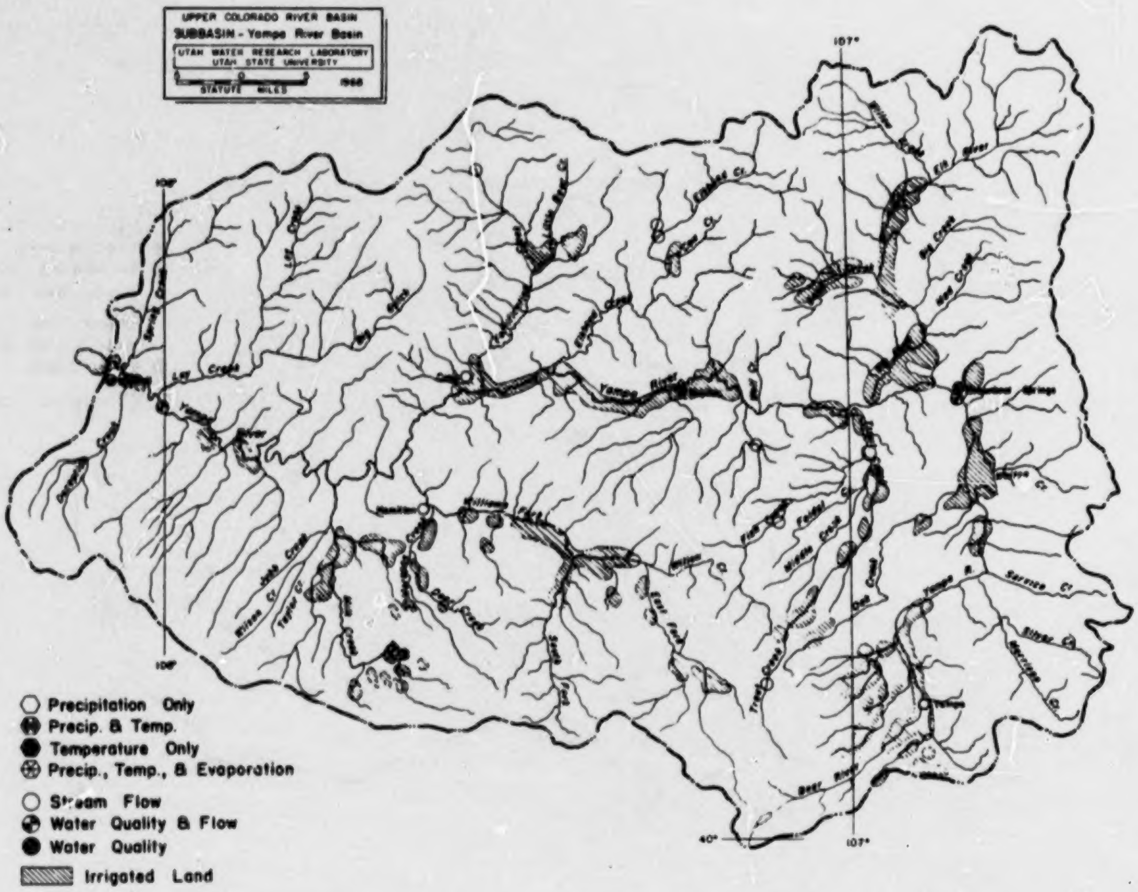

UPPER COLORADO RIVER BASIN
SUBBASIN - Yampa River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
0
STATUTE MILES
107°
108°
40°
Yampa River
Elk River
Williams Fork
Bear River
Lay Creek
Wilson Cr
Taylor Cr
Precipitation Only
Precip. & Temp.
Temperature Only
Precip., Temp., & Evaporation
Stream Flow
Water Quality & Flow
Water Quality
Irrigated Land

Figure A7. Yampa River basin, hydrologic and salinity subbasin.

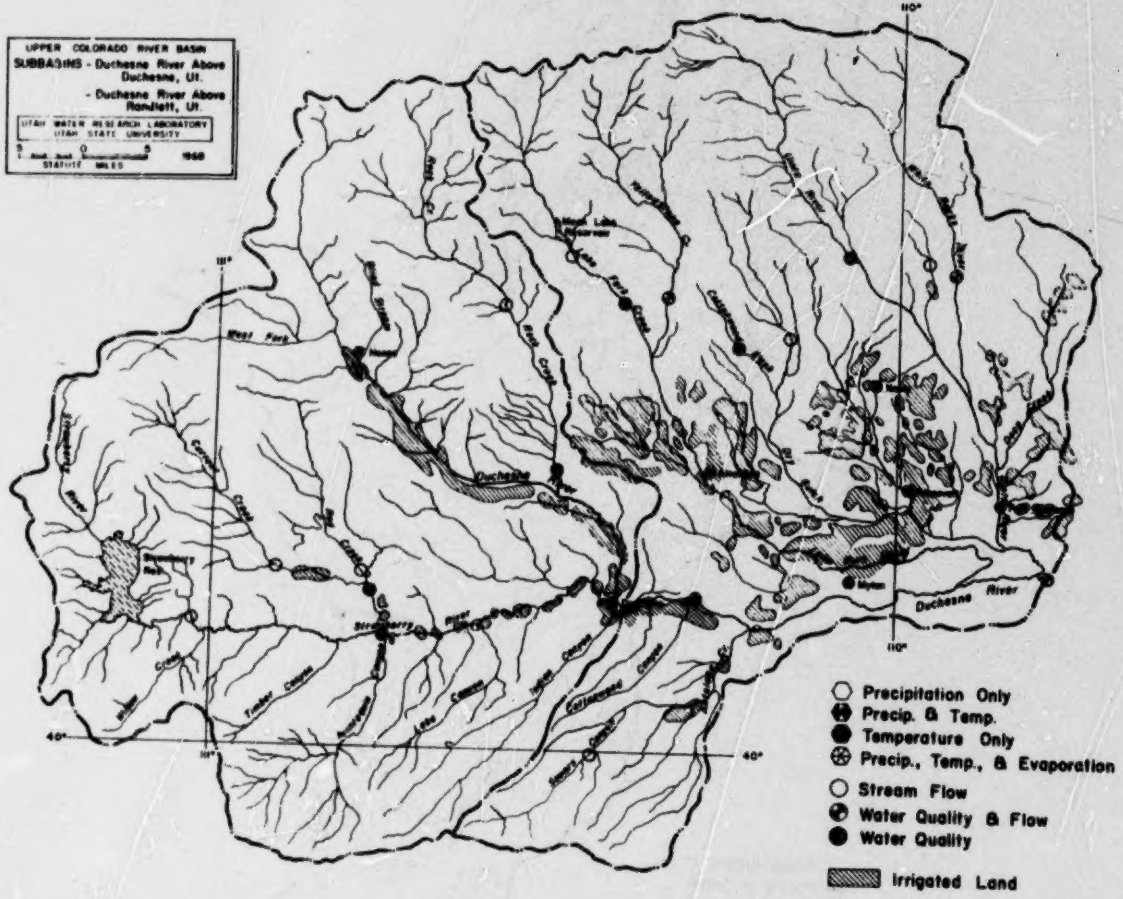

UPPER COLORADO RIVER BASIN
SUBBASINS - Duchesne River Above Duchesne, Ut.
- Duchesne River Above Randlett, Ut.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
110°
111°
40°
West Fork
Duchesne
Strawberry River
Duchesne River
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A10. Duchesne River above Duchesne, Utah and Duchesne River above Randlett, Utah, hydrologic and salinity subbasins.

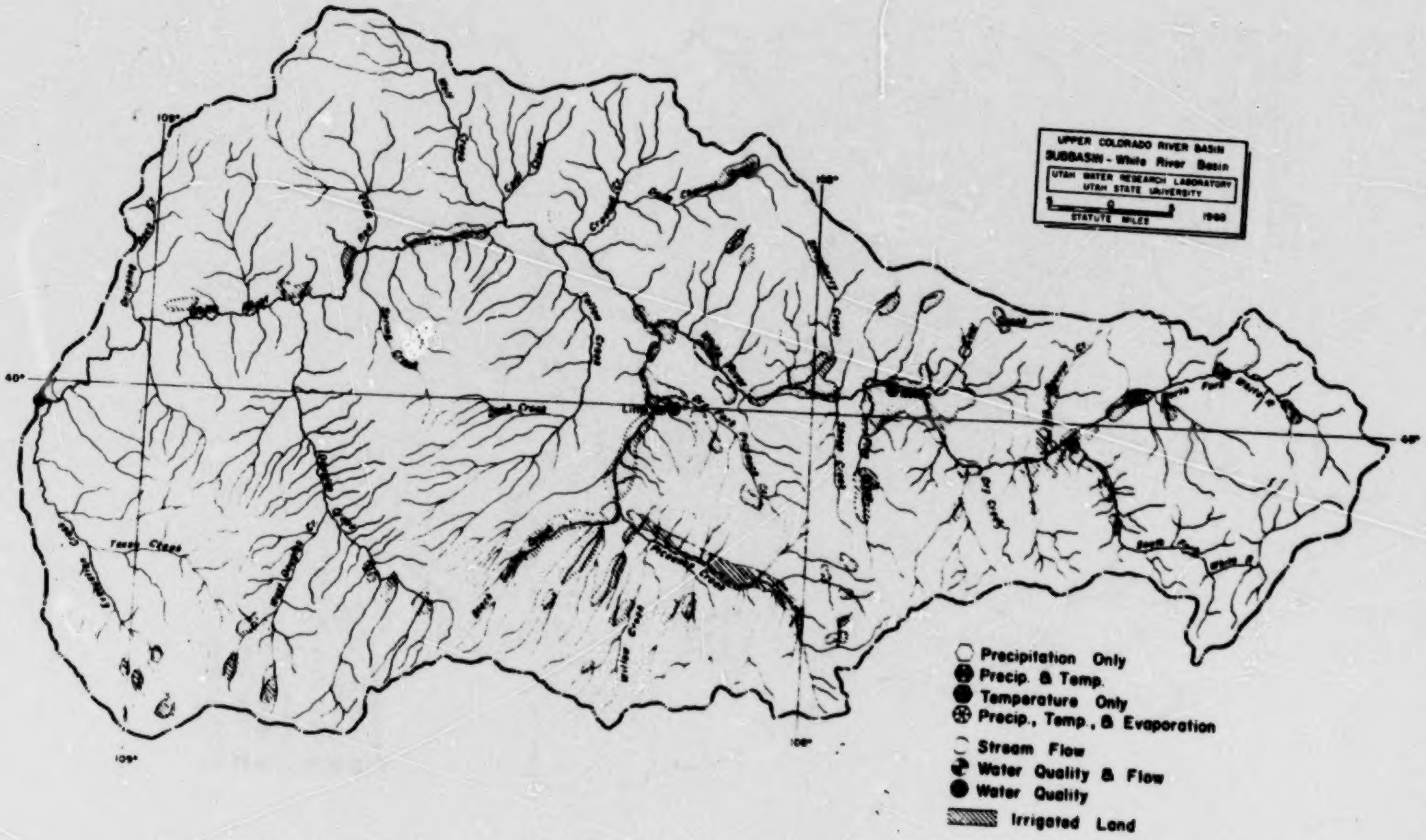

UPPER COLORADO RIVER BASIN
SUBBASIN - White River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1969
40°
108°
109°
Dry Creek
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A11. White River basin, hydrologic and salinity subbasin.

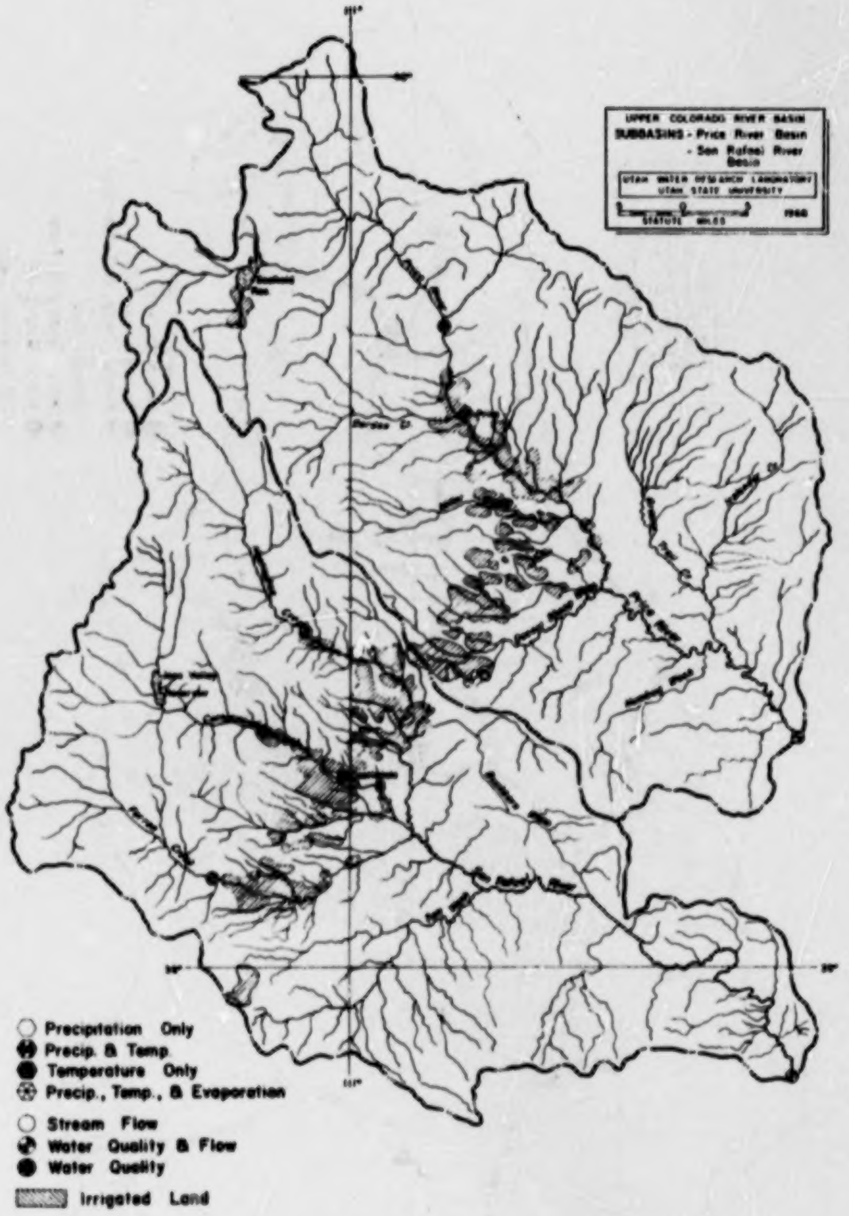

UPPER COLORADO RIVER BASIN
SUBBASINS - Price River Basin
- San Rafael River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1966
Precipitation Only
Precip. & Temp.
Temperature Only
Precip., Temp., & Evaporation
Stream Flow
Water Quality & Flow
Water Quality
Irrigated Land

Figure A12. Price River basin and San Rafael River basin, hydrologic and salinity subbasin.

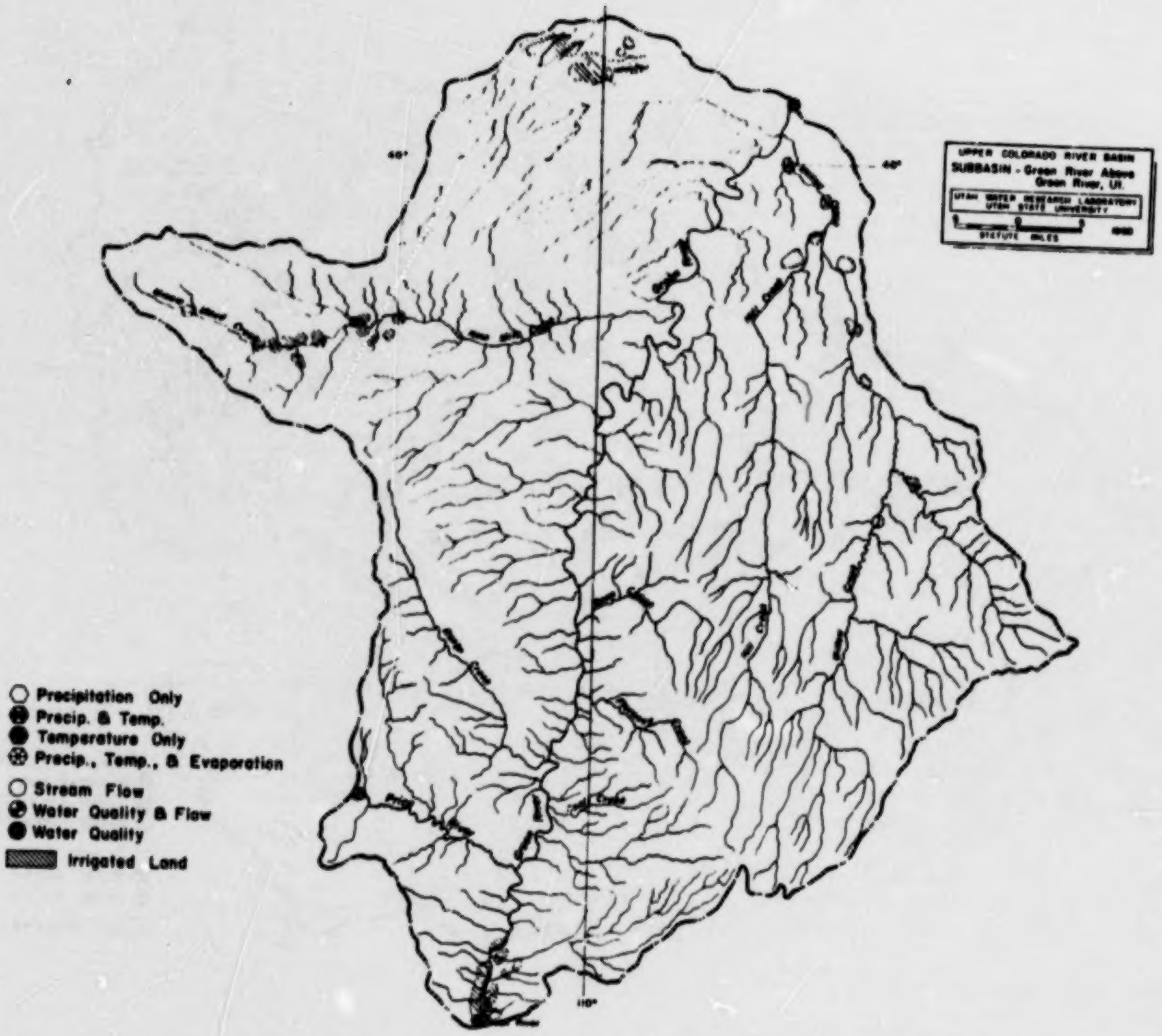

UPPER COLORADO RIVER BASIN
SUBBASIN - Green River Above Green River, Ut.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
40°
40°
110°
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A13. Green River above Green River, Utah, hydrologic and salinity subbasin.

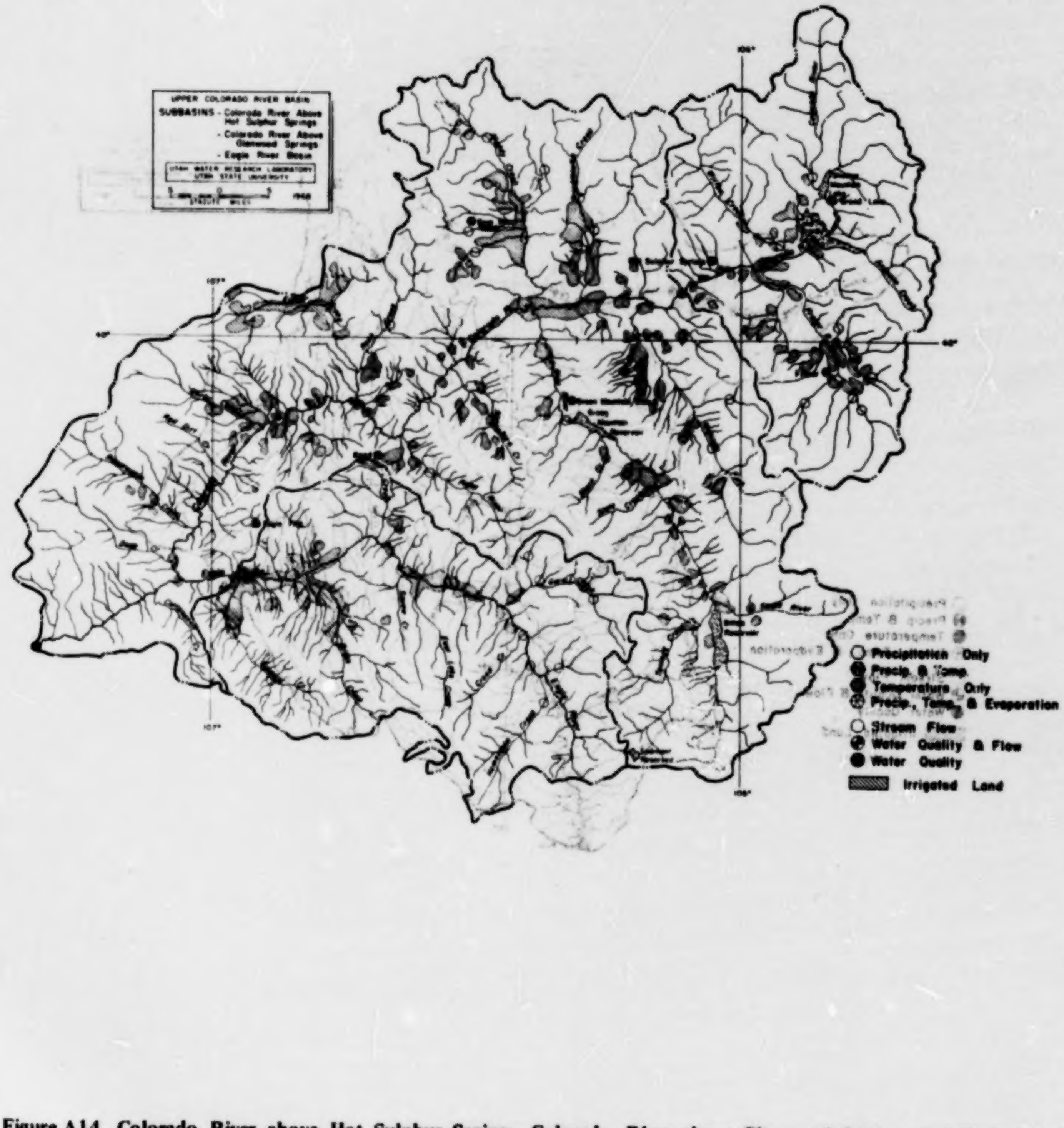

UPPER COLORADO RIVER BASIN
SUBBASINS - Colorado River Above Hot Sulphur Springs
- Colorado River Above Glenwood Springs
- Eagle River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1968
107°
106°
40°
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
● Precip., Temp. & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A14. Colorado River above Hot Sulphur Springs, Colorado, River above Glenwood Springs, and Eagle River basin, hydrologic and salinity subbasins.

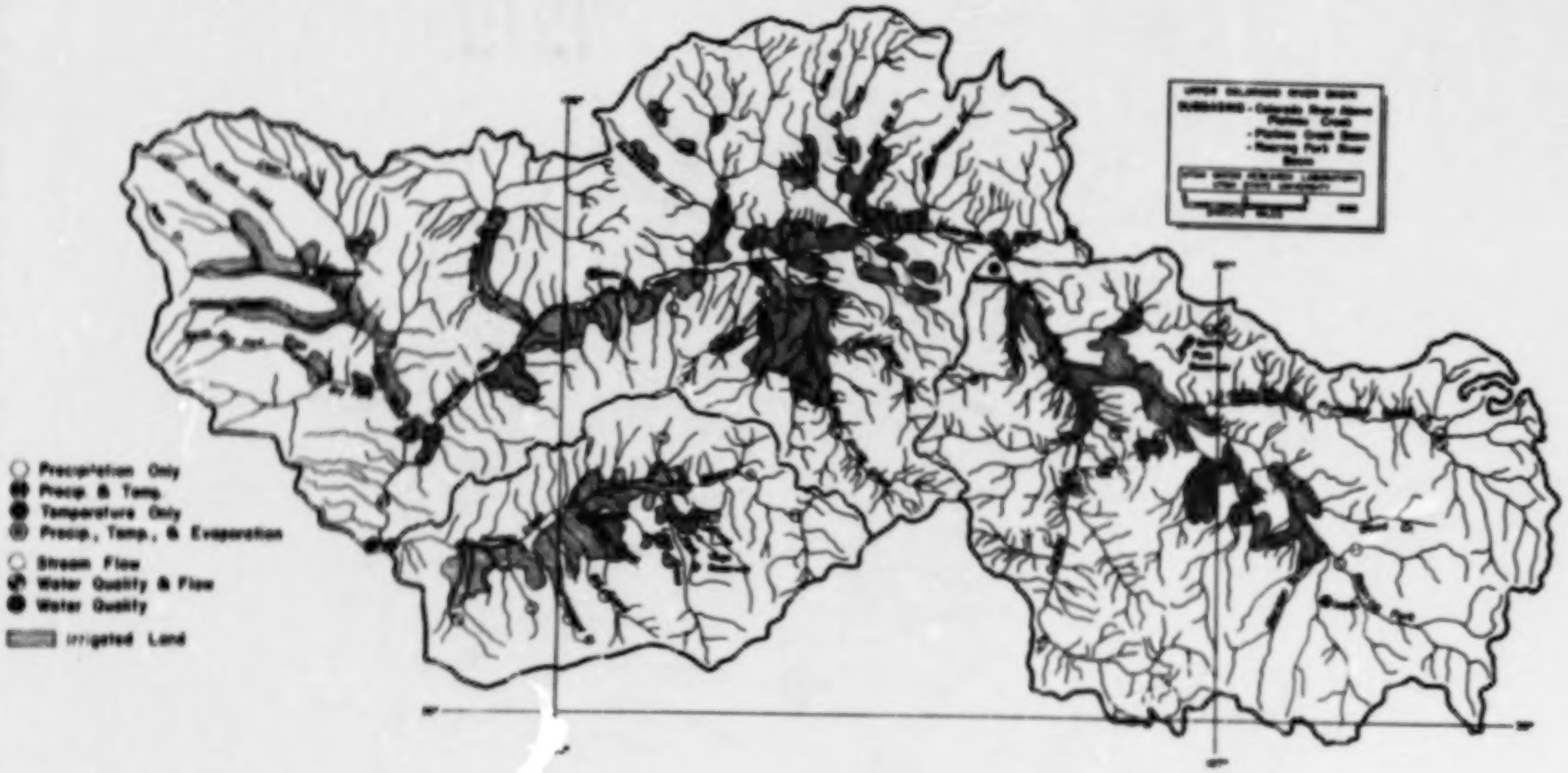

UPPER COLORADO RIVER BASIN
SUBBASINS - Colorado River Above Plateau Creek
- Plateau Creek Basin
- Roaring Fork River Basin
○ Precipitation Only
● Precip & Temp.
● Temperature Only
● Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A15. Colorado River above Plateau Creek, Plateau Creek, and Roaring Fork River basin, hydrologic and salinity subbasins.

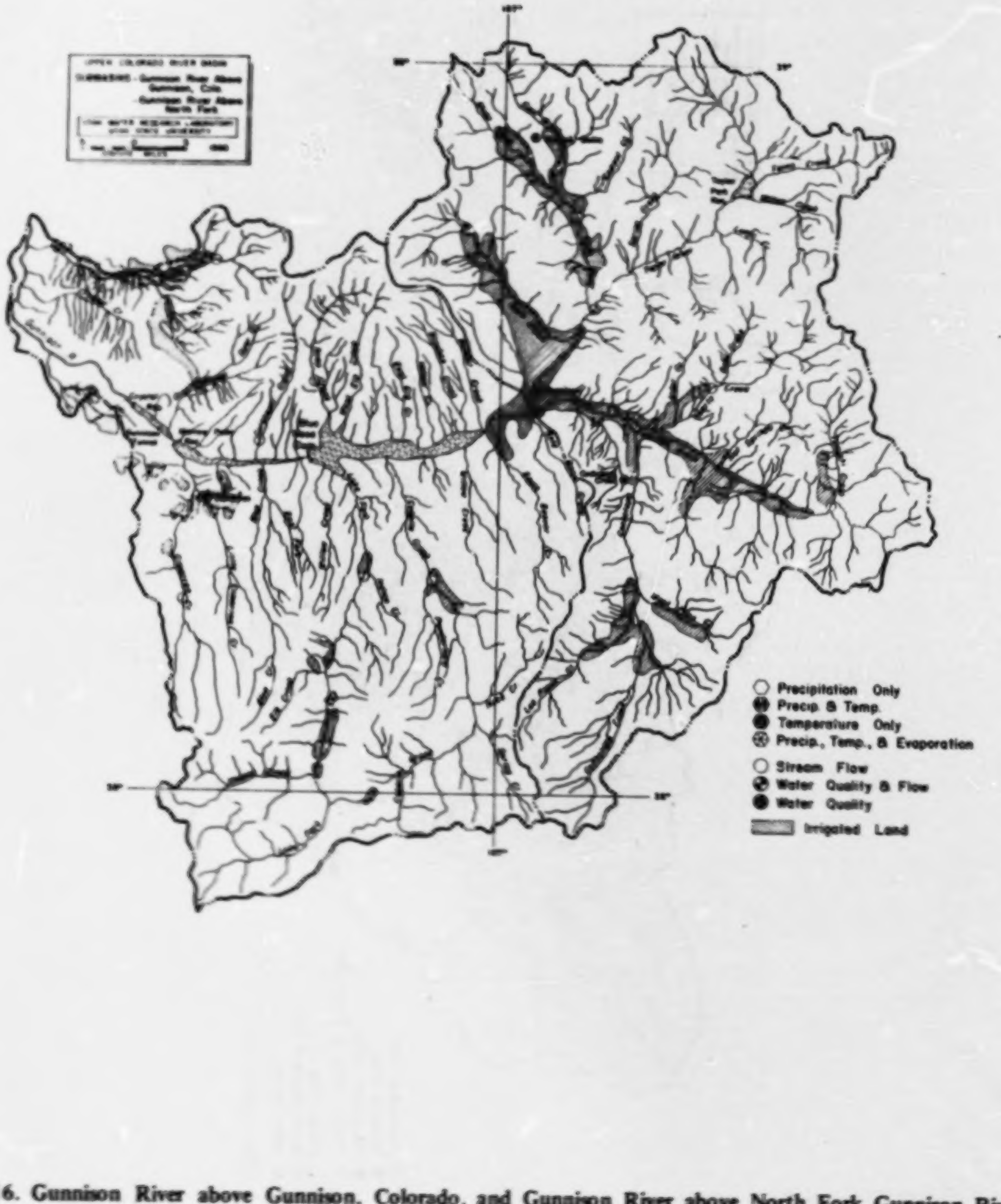

UPPER COLORADO RIVER BASIN
SUBBASINS - Gunnison River Above Gunnison, Colo.
- Gunnison River Above North Fork
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
Precipitation Only
Precip. & Temp.
Temperature Only
Precip., Temp., & Evaporation
Stream Flow
Water Quality & Flow
Water Quality
Irrigated Land

Figure A16. Gunnison River above Gunnison, Colorado, and Gunnison River above North Fork Gunnison River, hydrologic and salinity subbasins.

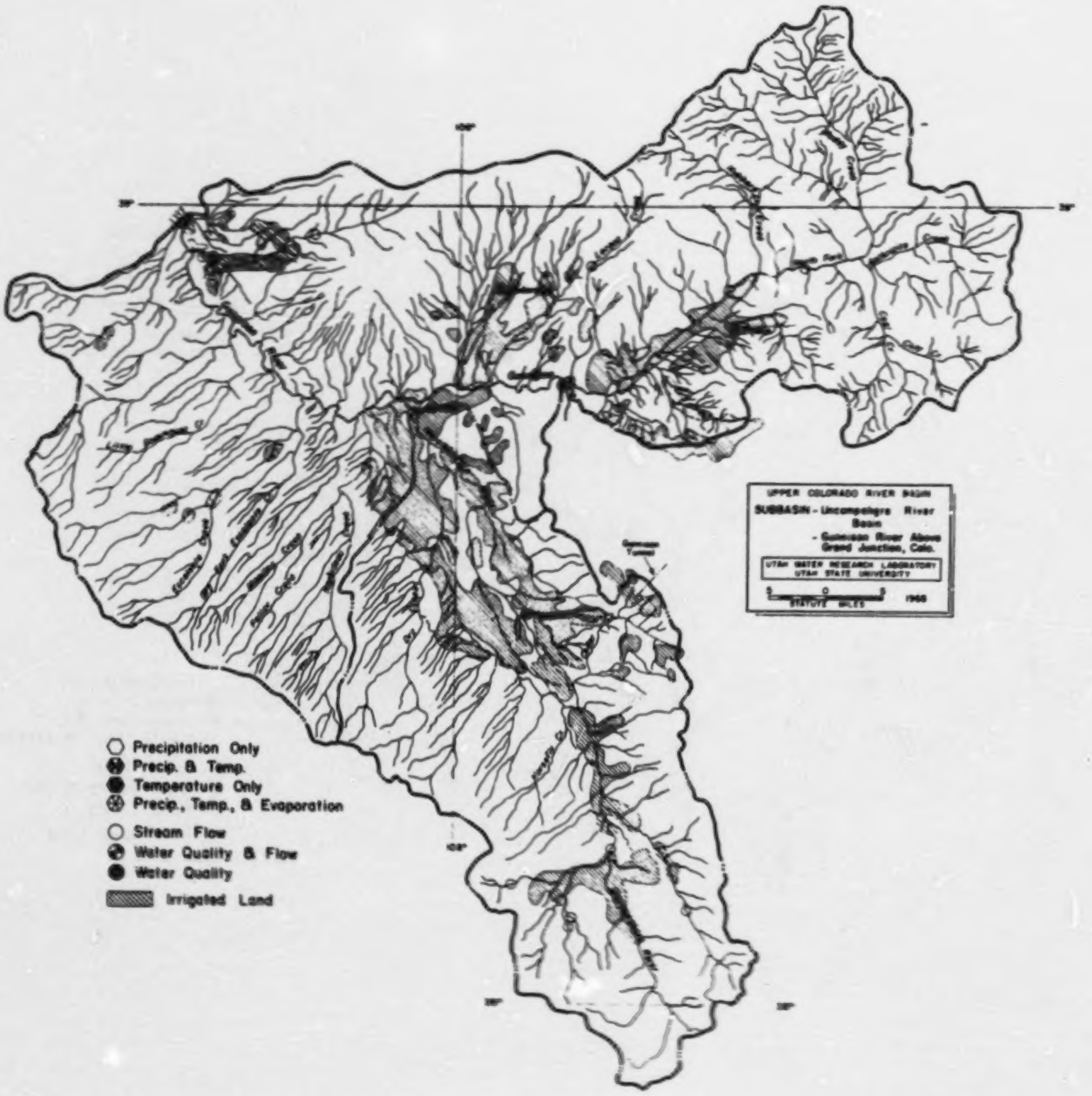

UPPER COLORADO RIVER BASIN
SUBBASIN - Uncompahgre River Basin
- Gunnison River Above Grand Junction, Colo.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
Gunnison Tunnel
108°
39°
38°
⬡ Precipitation Only
⬢ Precip. & Temp.
⬢ Temperature Only
⬡ Precip., Temp., & Evaporation
○ Stream Flow
◕ Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A17. Gunnison River above Grand Junction, Colorado, and Uncompahgre River basin, hydrologic and salinity subbasins.

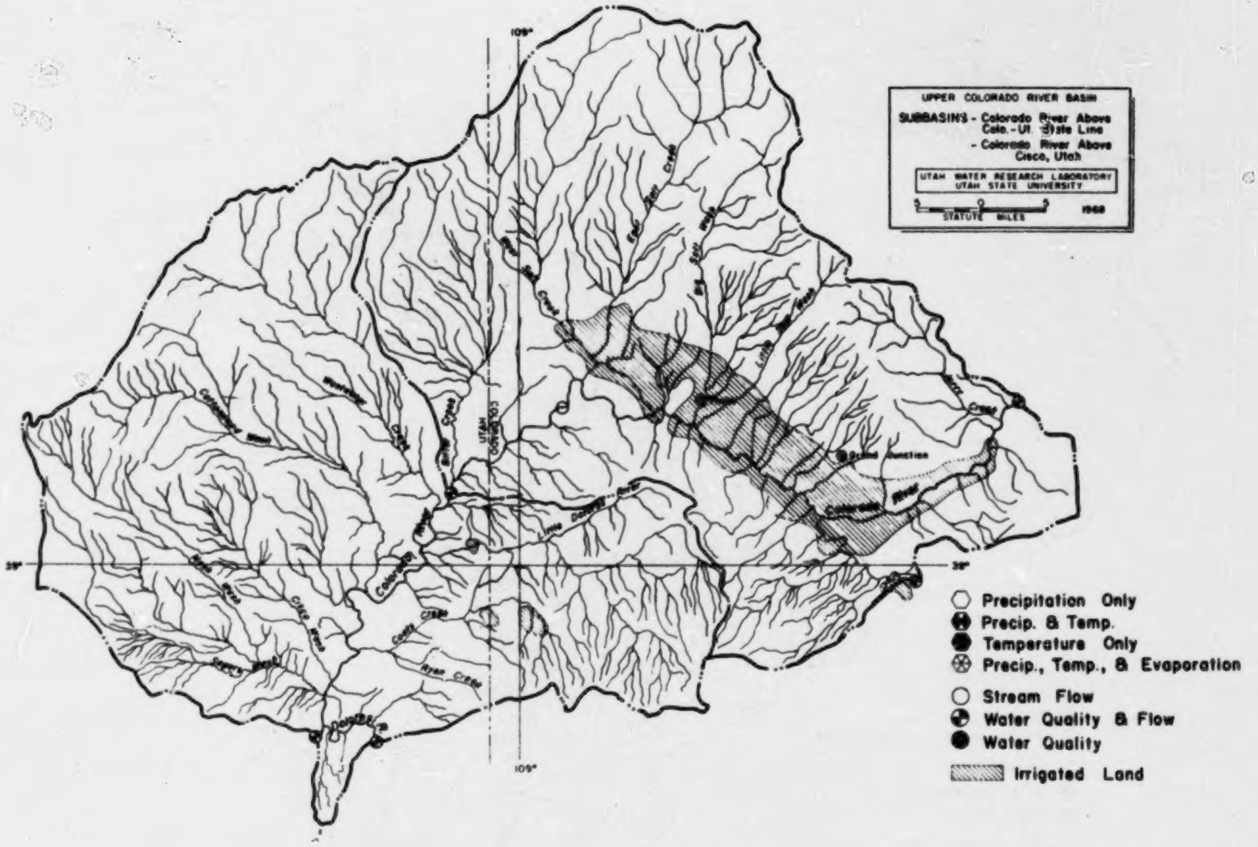
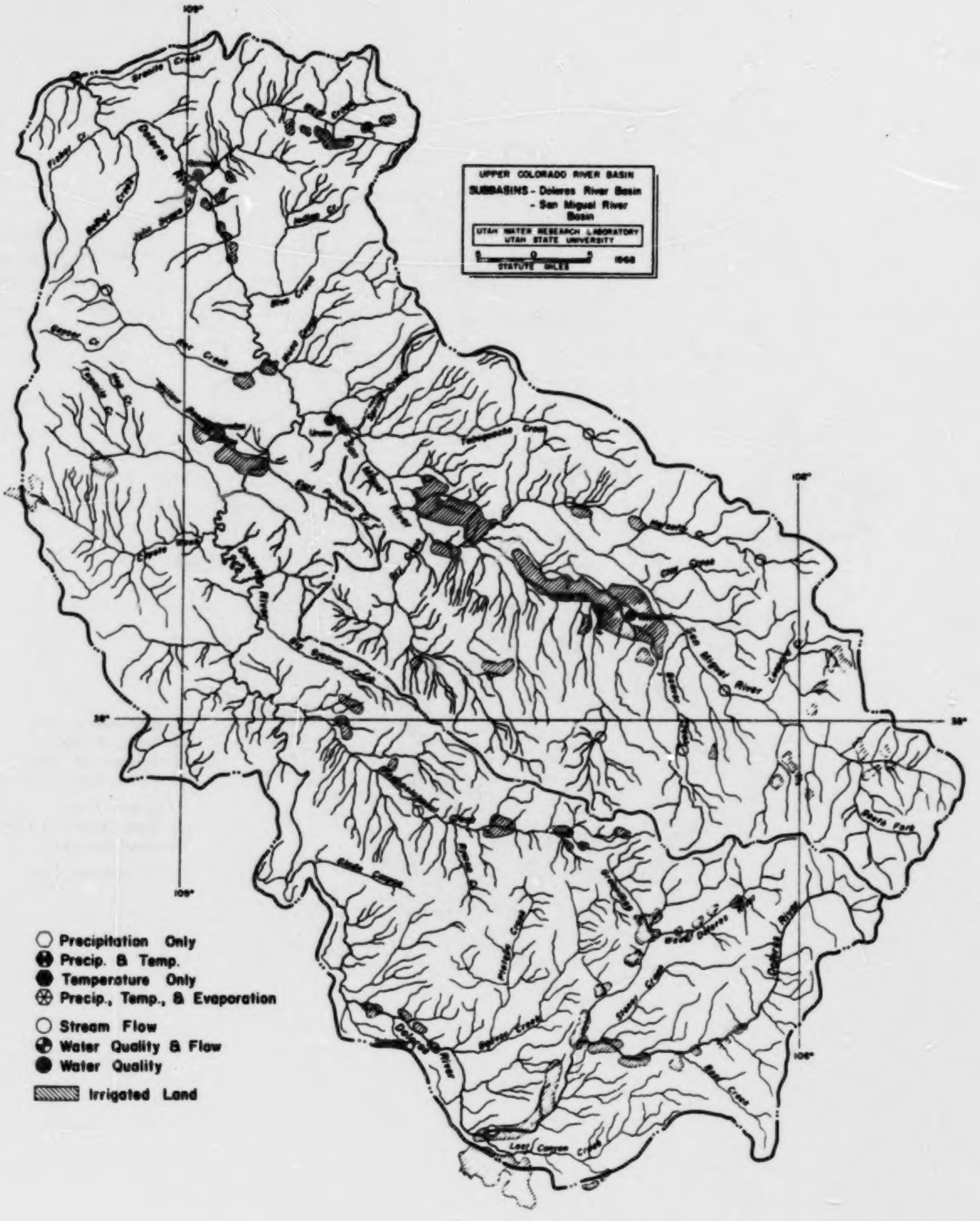

109°
UPPER COLORADO RIVER BASIN
SUBBASINS - Colorado River Above Colo.-Ut. State Line
- Colorado River Above Cisco, Utah
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1968
UTAH
COLORADO
Grand Junction
Colorado River
39°
39°
109°
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A18. Colorado River above Colorado - Utah State Line and Colorado River above Cisco, Utah, hydrologic and salinity subbasins.



UPPER COLORADO RIVER BASIN
SUBBASINS - Dolores River Basin
- San Miguel River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
109°
108°
38°
San Miguel River
Dolores River
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A19. Dolores River basin and San Miguel River basin, hydrologic and salinity subbasins.

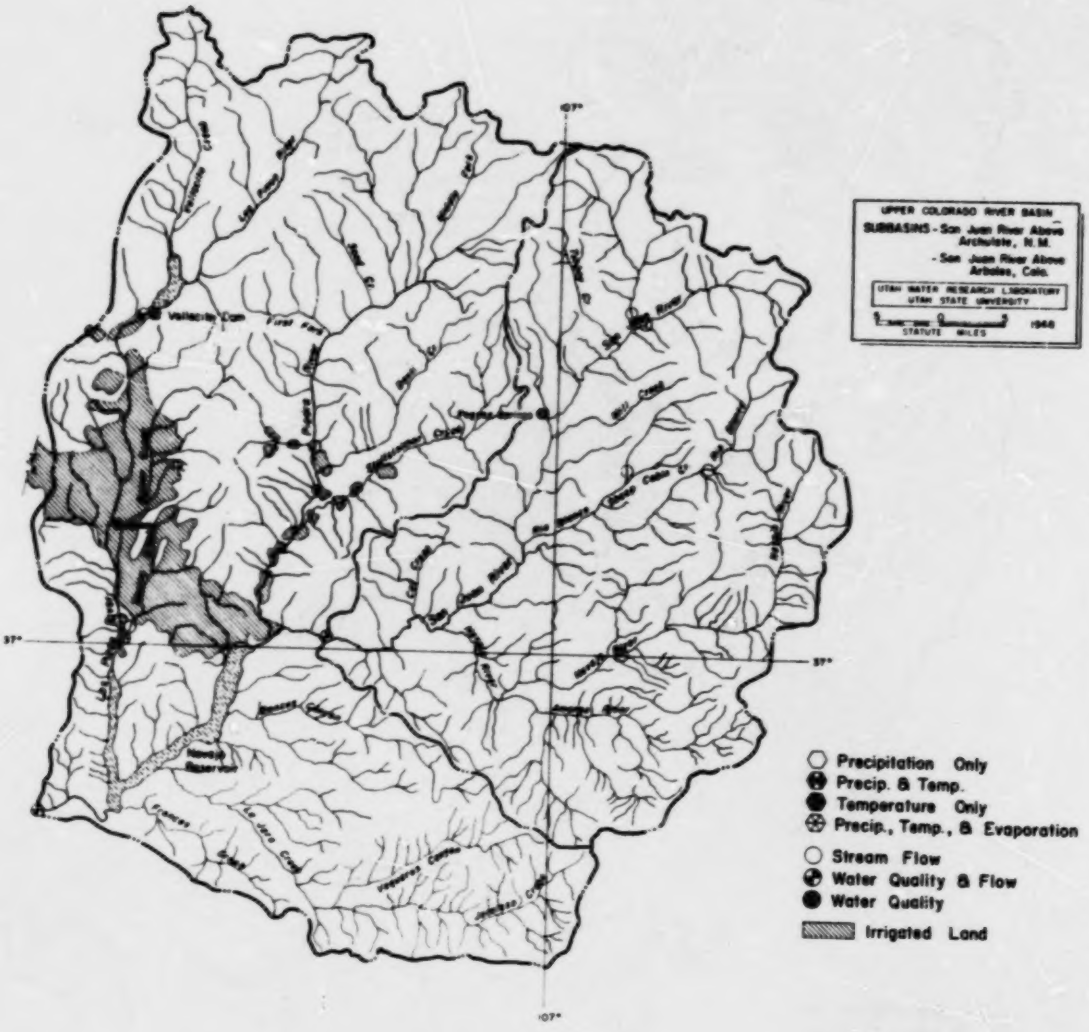

UPPER COLORADO RIVER BASIN
SUBBASINS - San Juan River Above Archuleta, N.M.
- San Juan River Above Arboles, Colo.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1968
107°
37°
Vallecito Dam
First Fork
Navajo Reservoir
San Juan River
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A20. San Juan River above Archuleta, New Mexico, and San Juan River above Arboles, Colorado, hydrologic and salinity subbasins.

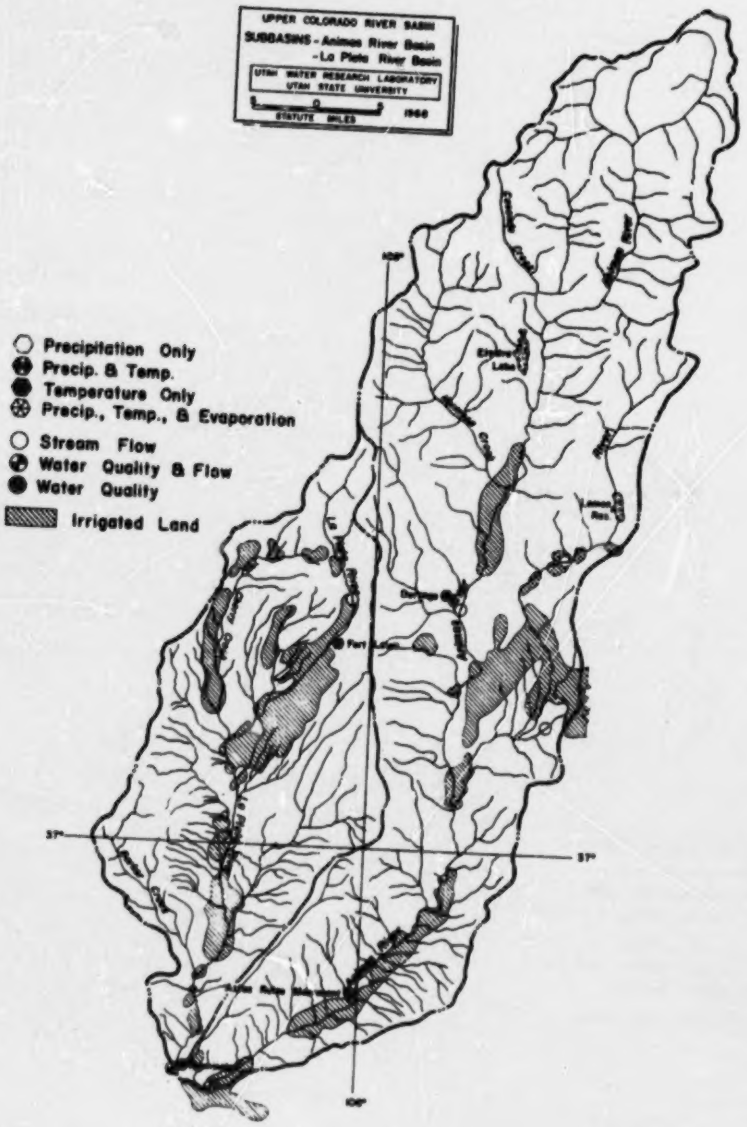

UPPER COLORADO RIVER BASIN
SUBBASINS - Animas River Basin
- La Plata River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land
108°
37°
37°
108°
Electra Lake
Lemon Res.
Durango
Fort Lewis

Figure A21. Animas River basin and La Plata River basin, hydrologic and salinity subbasins.

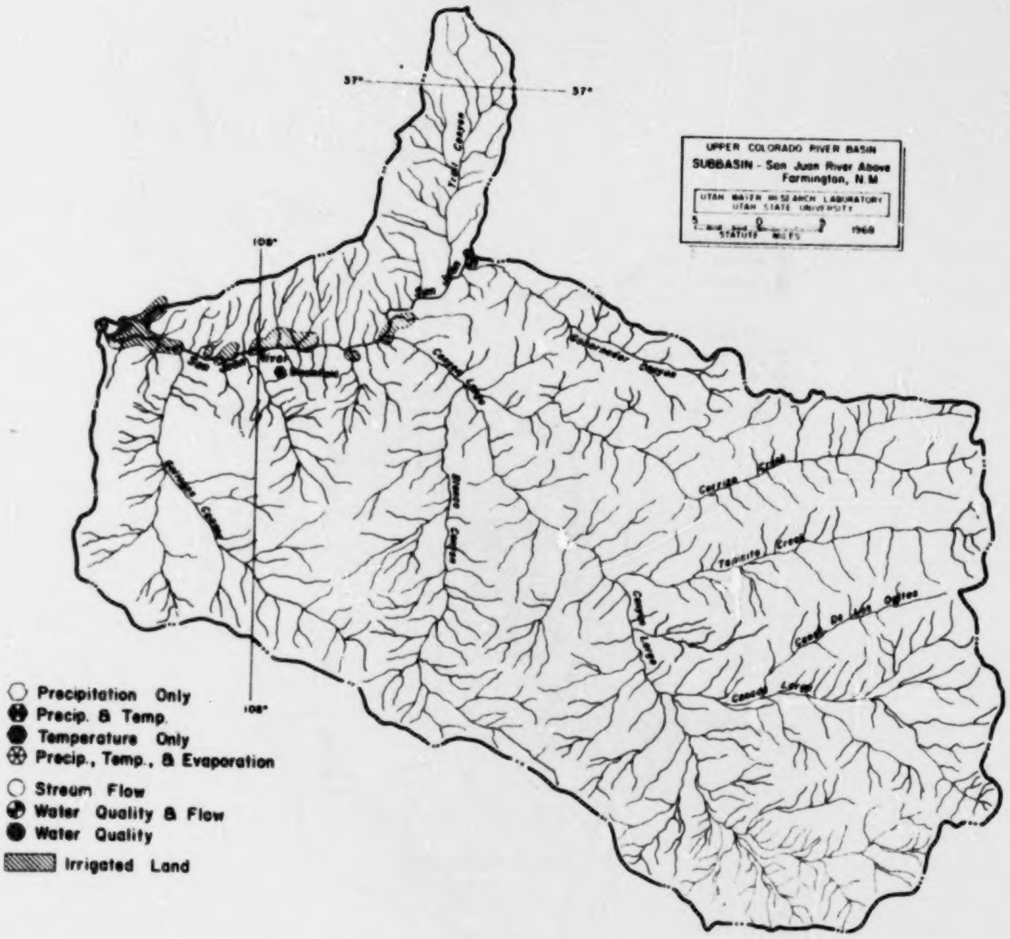

37°
37°
108°
108°
UPPER COLORADO RIVER BASIN
SUBBASIN - San Juan River Above Farmington, N.M
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5
0
STATUTE MILES
1968
San Juan River
Carrizo Creek
Tapacito Creek
Blanco Canyon
Canada Larga
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A22. San Juan River above Farmington, New Mexico, hydrologic and salinity subbasins.

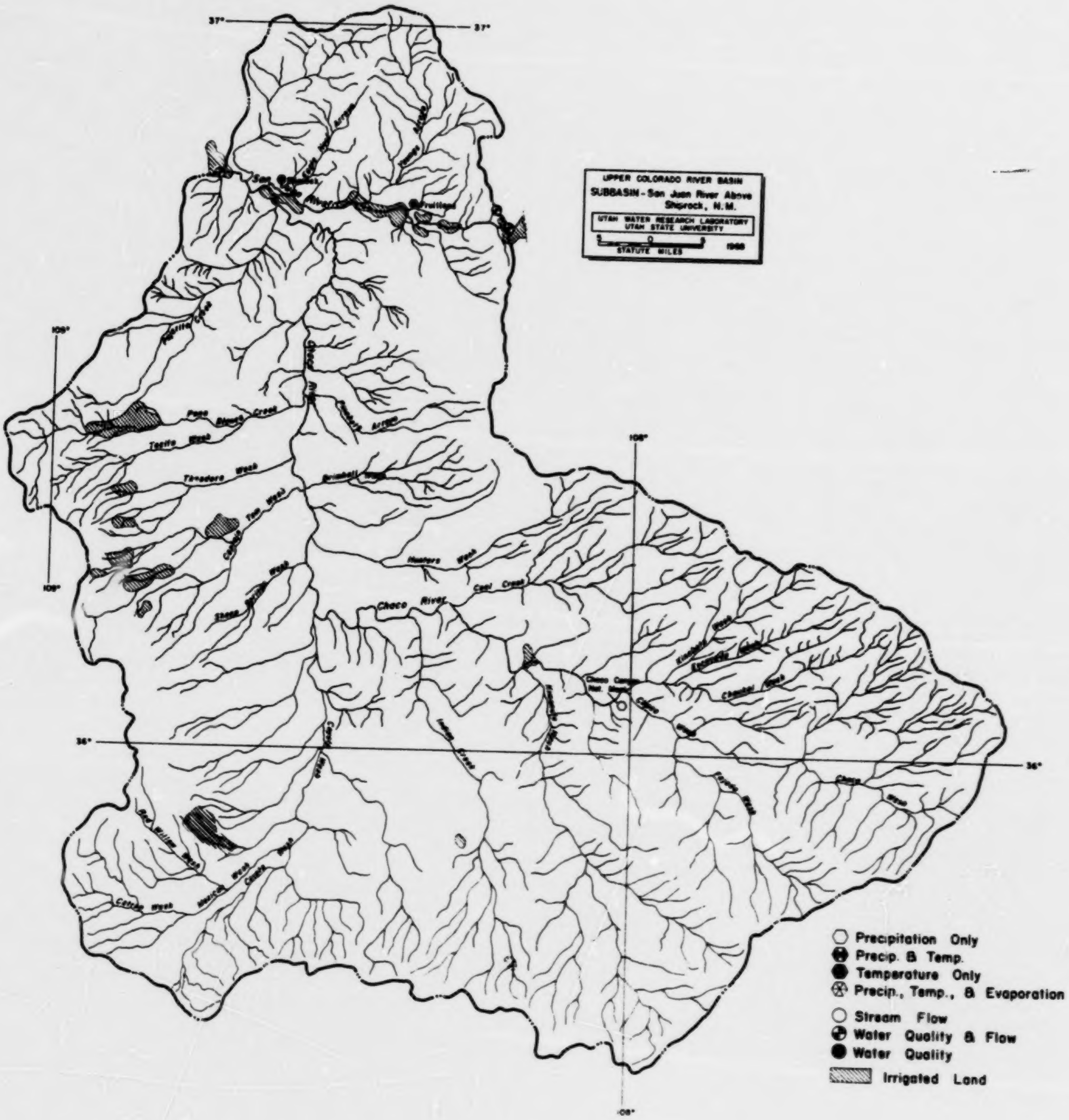
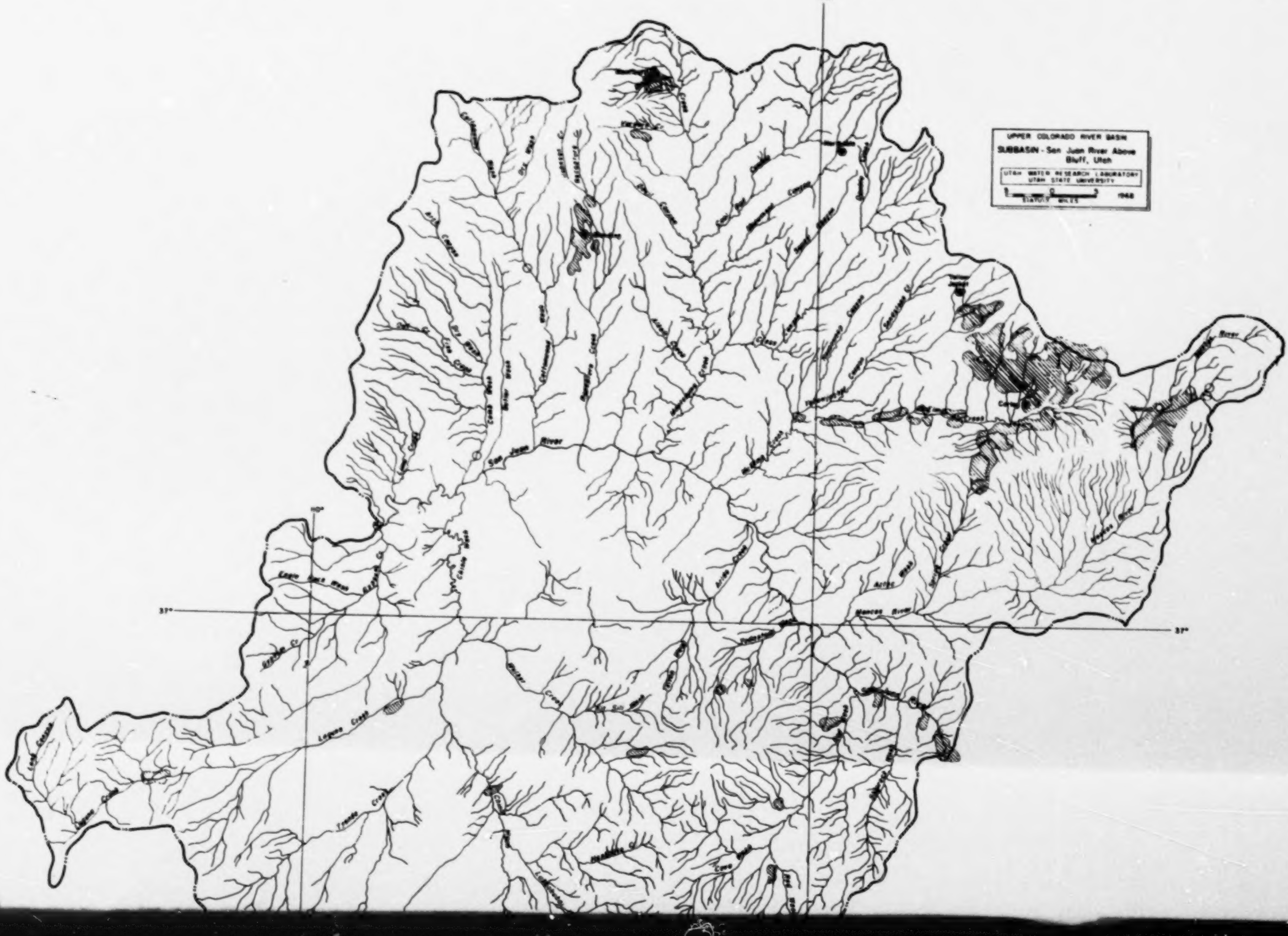

UPPER COLORADO RIVER BASIN
SUBBASIN - San Juan River Above Shiprock, N.M.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1969
37°
36°
108°
San Juan River
Farmington
Chaco River
Coal Creek
Hunters Wash
Brimhall Wash
Pena Blanca Creek
Tocito Wash
Tanadoro Wash
Coyote Tom Wash
Chaco Canyon Nat. Mon.
Chaco Wash
Red Willow Wash
Coyote Wash
Indian Creek
Catron Wash
⬡ Precipitation Only
Precip. & Temp.
⬢ Temperature Only
Precip., Temp., & Evaporation
○ Stream Flow
Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A23. San Juan River above Shiprock, New Mexico, hydrologic and salinity subbasin.


UPPER COLORADO RIVER BASIN
SUBBASIN - San Juan River Above Bluff, Utah
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
1968
108°
107°
37°
San Juan River
Mancos River

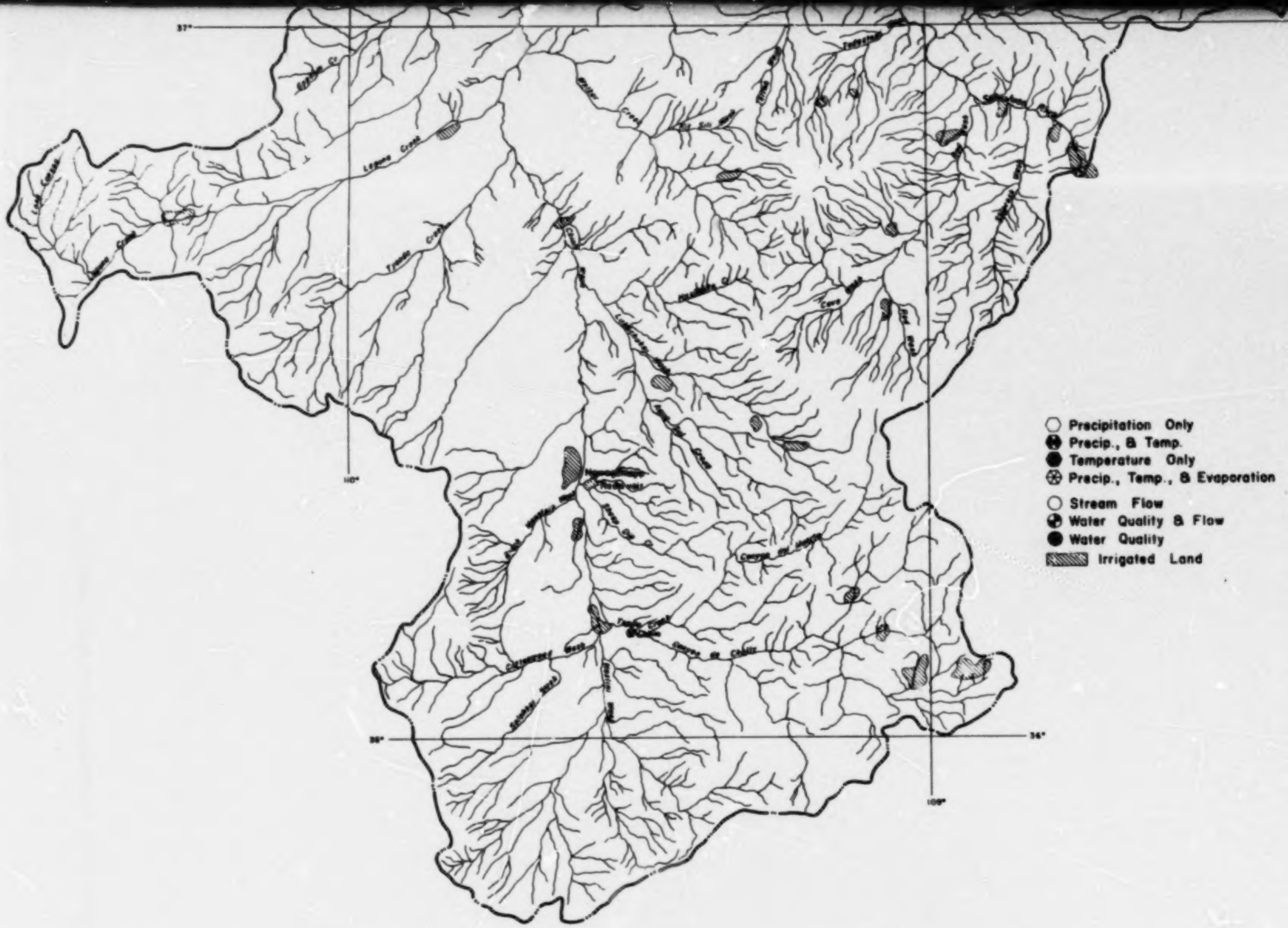

37°
37°
110°
109°
36°
36°
Laguna Creek
Laguna Creek
Tyende Creek
Canyon del Muerto
Canyon de Chelly
○ Precipitation Only
● Precip., & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land

Figure A24. San Juan River above Bluff, Utah, hydrologic and salinity subbasin.

Preceding page blank

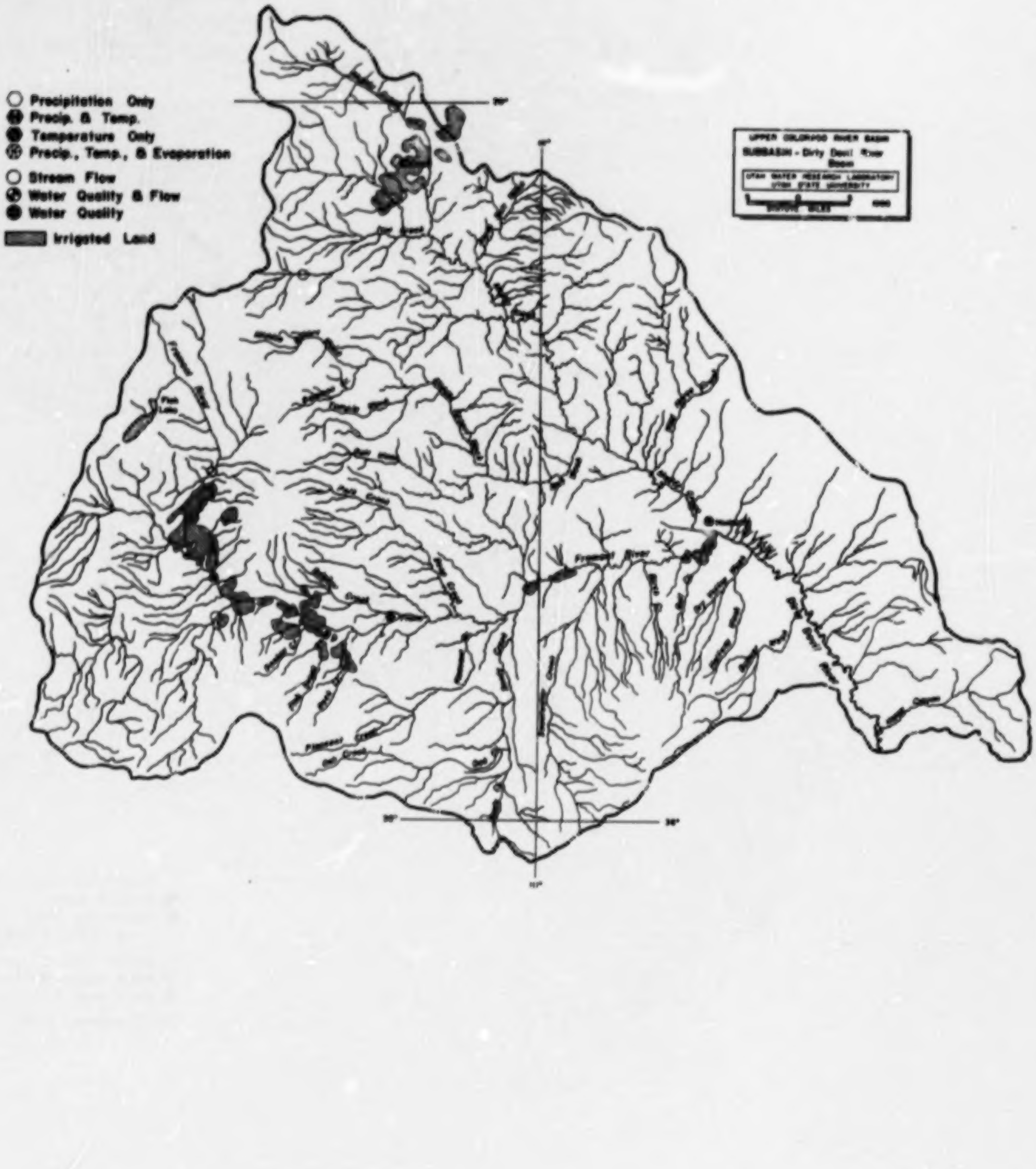

○ Precipitation Only
Precip. & Temp.
● Temperature Only
Precip., Temp., & Evaporation
○ Stream Flow
Water Quality & Flow
● Water Quality
▨ Irrigated Land
UPPER COLORADO RIVER BASIN
SUBBASIN - Dirty Devil River Basin
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
Fish Lake
Fremont River

Figure A25. Dirty Devil River basin, hydrologic and salinity subbasin.

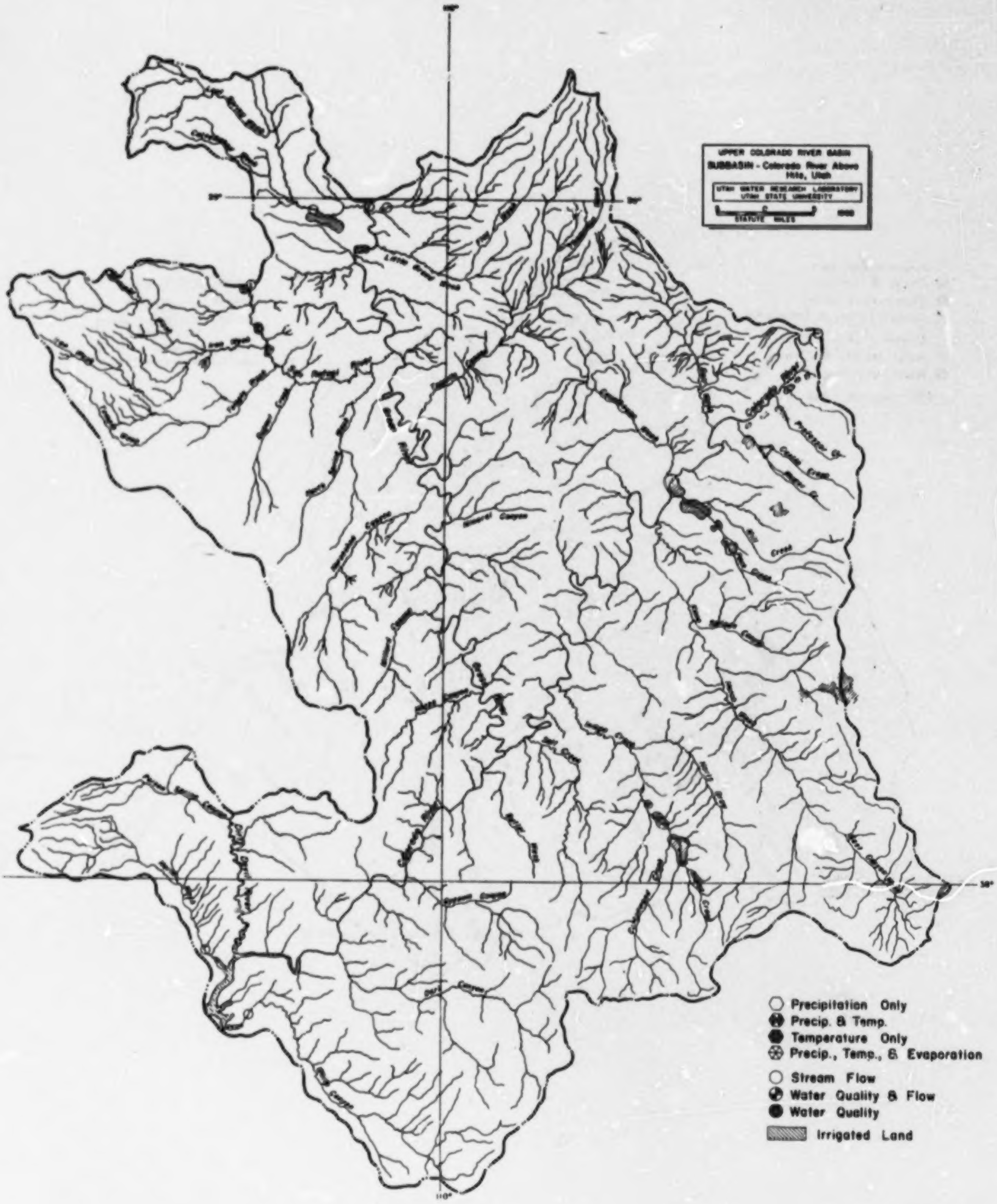
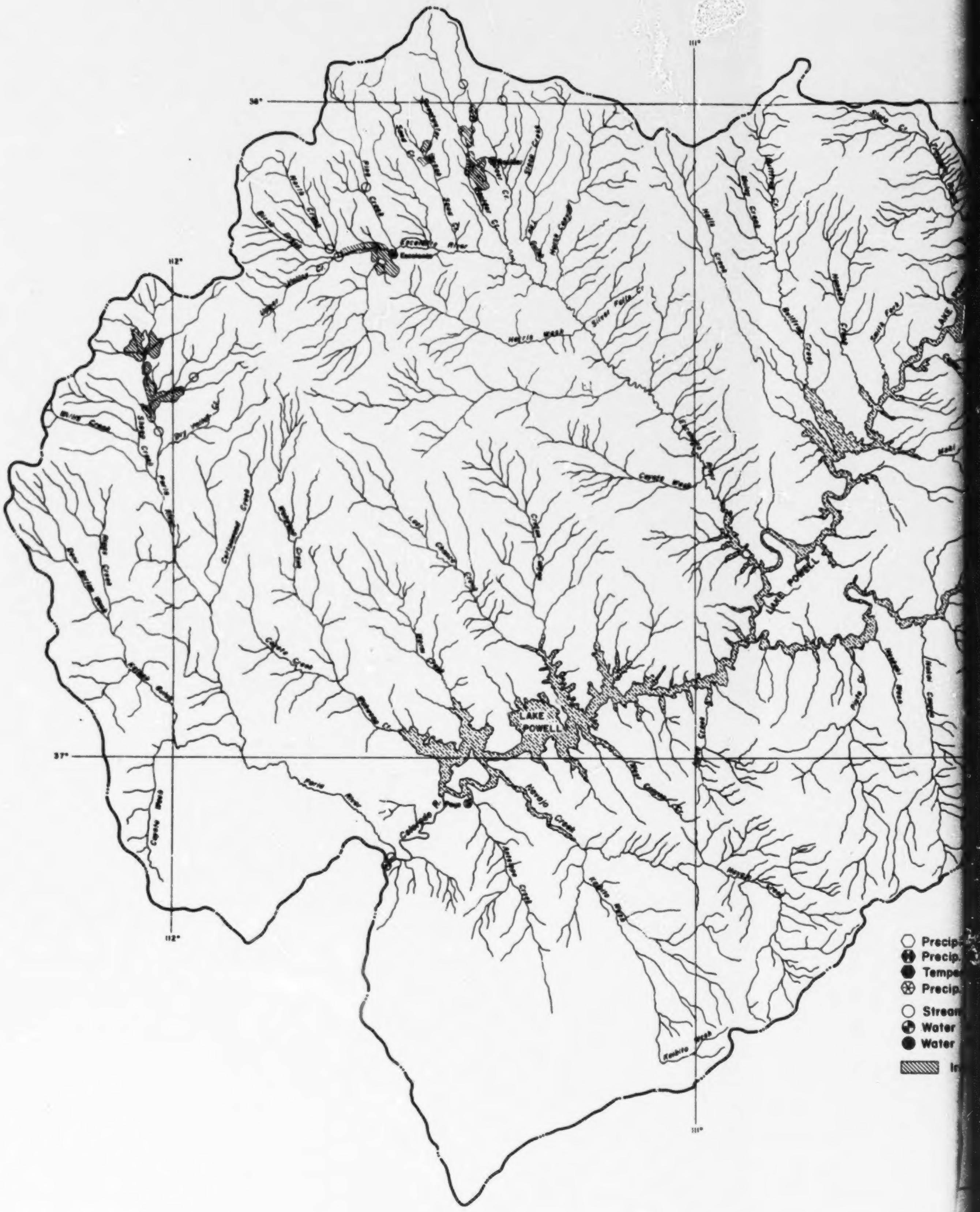
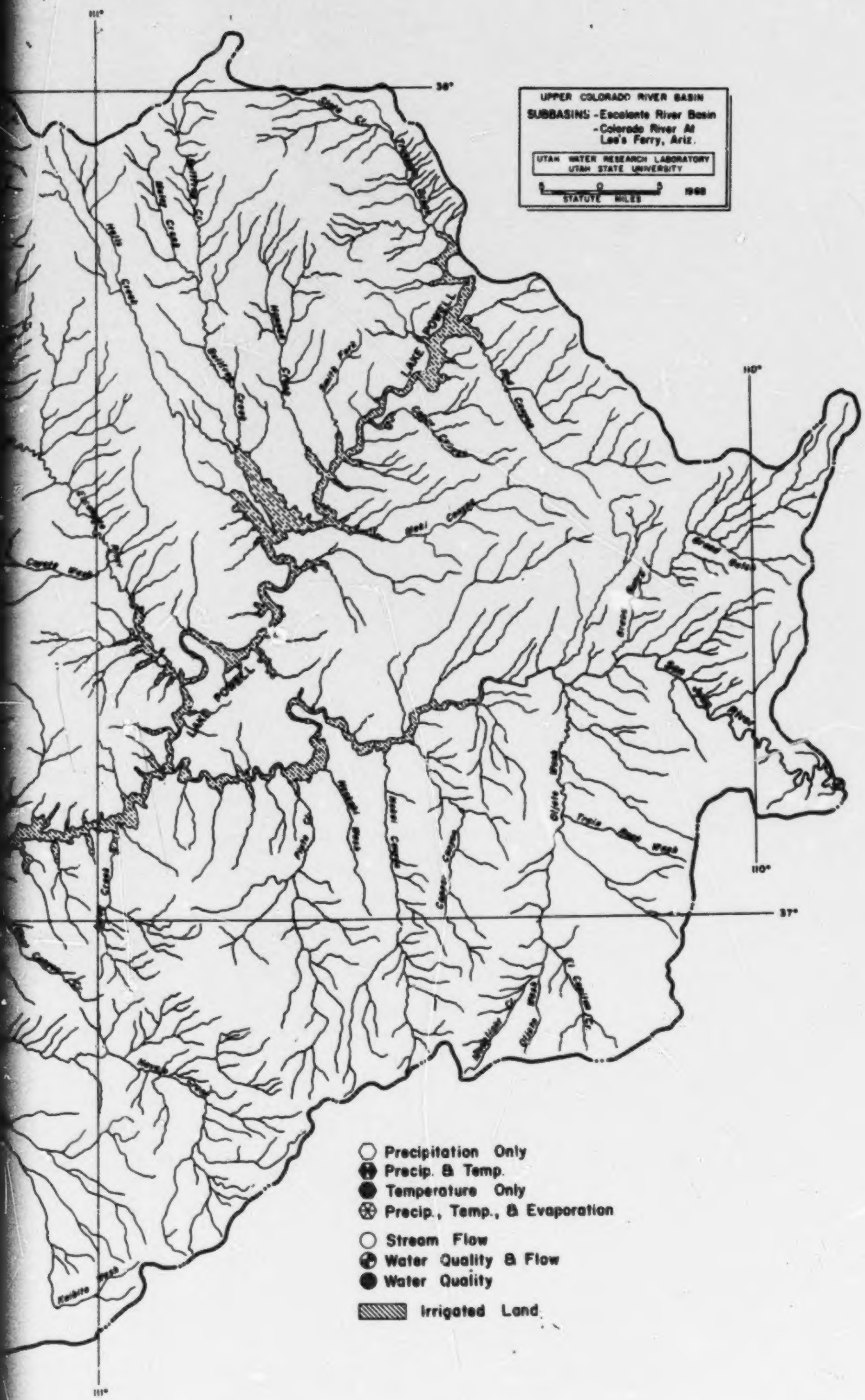

UPPER COLORADO RIVER BASIN
SUBBASIN - Colorado River Above Hite, Utah
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
STATUTE MILES
○ Precipitation Only
● Precip. & Temp.
● Temperature Only
⊛ Precip., Temp., & Evaporation
○ Stream Flow
● Water Quality & Flow
● Water Quality
▨ Irrigated Land
110°

Figure A26. Colorado River above Hite, Utah, hydrologic and salinity subbasin.

Figure A27. Escalante River basin and Colorado River at Lee Ferry, Arizona, hydrologic and salinity subbasins.


38°
37°
112°
111°
Pine Creek
Sand Cr.
Escalante River
Escalante
Harris Wash
Silver Falls Cr.
Halls Creek
Cottonwood Creek
Last Chance Creek
Wahweap Creek
LAKE POWELL
LAKE POWELL
Paria River
Colorado R.
Navajo Creek
Kaibito Wash
Precip.
Precip.
Temper
Precip.
Stream
Water
Water
In


UPPER COLORADO RIVER BASIN
SUBBASINS -Escalante River Basin
-Colorado River At Lee's Ferry, Ariz.
UTAH WATER RESEARCH LABORATORY
UTAH STATE UNIVERSITY
5 0 5
STATUTE MILES
1968
111°
38°
110°
37°
LAKE POWELL
Precipitation Only
Precip. & Temp.
Temperature Only
Precip., Temp., & Evaporation
Stream Flow
Water Quality & Flow
Water Quality
Irrigated Land

APPENDIX B

Tabulation of Irrigated Lands, Acreages, and Hydrologic Drainage Areas

Table B-1. Subbasin areas and location of irrigated acreage within the Green Division.

Subbasin	Irrigated Acreage Within Subbasin		Total Irrigated Acreage in Subbasin
	Area	Acreage	
NEW FORK RIVER BASIN	New Fork Tributary Area	44,000	
(Total Area: 1230 mi.^{2})	TOTAL		44,000
GREEN RIVER ABOVE LABARGE, WYOMING	Source of Green River	0	
	Intervening Area	4,000	
	Beaver Creek Tributary Area	4,000	
(Total Area: 2320 mi.^{2})	Intervening Area	3,000	
	Horse Creek Tributary Area	8,000	
	Intervening Area	11,000	
	Cottonwood Creek Tributary Area	16,000	
	Intervening Area	6,500	
	Piney Creek Tributary Area	36,000	
	Intervening Area	3,000	
	TOTAL		91,500
GREEN RIVER ABOVE FONTENELLE RESERVOIR	LaBarge Creek Tributary Area	6,000	
	Fontenelle Creek Tributary Area	3,600	
(Total Area: 950 mi.^{2})			
	TOTAL		9,600
BIG SANDY CREEK BASIN	Big Sandy Creek Tributary Area	18,000	
(Total Area: 1610 mi.^{2})			
	TOTAL		18,000
GREEN RIVER ABOVE GREEN RIVER, WYOMING	Intervening Area	1,500	
(Total Area: 1391 mi.^{2})			
	TOTAL		1,500
BLACKS FORK RIVER BASIN	Source of Blacks Fork	0	
	Muddy Creek Tributary Area	4,000	
(Total Area: 3100 mi.^{2})	Blacks Fork Tributary Area	51,000	
	Hams Fork Tributary Area	10,500	
	TOTAL		65,500
GREEN RIVER ABOVE FLAMING GORGE DAM	Intervening Area	500	
	Henry Fork Tributary Area (3200 in Utah)	17,500	
(Total Area: 4500 mi.^{2})	Sheep Creek Tributary Area	5,500	
	TOTAL		23,500
LITTLE SNAKE RIVER BASIN	Little Snake River Tributary Area (7700 in Colorado)	21,600	
(Total Area: 3600 mi.^{2})			
	TOTAL		21,600
YAMPA RIVER BASIN	Source of Yampa River	0	
	Intervening Area	28,500	
(Total Area: 3600 mi.^{2})	Elk River Tributary Area	9,700	
	Intervening Area	11,500	

Table B-1. Continued.

Subbasin	Irrigated Acreage Within Subbasin		Total Irrigated Acreage in Subbasin
	Area	Acreage	
	Fortification & Elkhead Creeks		
	Tributary Area	3,000	
	Intervening Areas	1,000	
	Williams Fork Tributary Area	5,000	
	Intervening Area	8,000	
	TOTAL		66,700
GREEN RIVER ABOVE JENSEN, UTAH	Intervening Area	1,500	
	Vermillion Creek	2,000	
	Intervening Area	1,000	
(Total Area: 3100 mi.^{2})	TOTAL		4,500
ASHLEY CREEK BASIN	Ashley Creek Tributary Area	23,000	
(Total Area: 386 mi.^{2})			
	TOTAL		23,000
DUCHESNE RIVER ABOVE DUCHESNE, UTAH	Duchesne River Above Duchesne Utah, Tributary Area	9,500	
(Total Area: 1700 mi.^{2})	Strawberry River Above Duchesne, Utah, Tributary Area	4,000	
	Intervening Area	1,500	
	TOTAL		15,000
DUCHESNE RIVER ABOVE RANDLETT, UTAH	Intervening Area	118,500	
(Total Area: 2220 mi.^{2})	TOTAL		118,500
WHITE RIVER BASIN	Source of White River Tributary Area	0	
	Piceance Creek	5,000	
(Total Area: 4020 mi.^{2})	Intervening Area	24,200	
	TOTAL		29,200
GREEN RIVER ABOVE OURAY, UTAH	Brush Creek Tributary Area	1,600	
	Intervening Area	7,900	
(Total Area: 1774 mi.^{2})	TOTAL		9,500
PRICE RIVER BASIN	Price River Tributary Area	16,500	
(Total Area: 1500 mi.^{2})	TOTAL		16,500
GREEN RIVER ABOVE GREEN RIVER, UTAH	Willow Creek Tributary Area	2,000	
	Minnie Maud Creek Tributary Area	1,500	
	Intervening Area	3,000	
(Total Area: 3600 mi.^{2})			
	TOTAL		6,500
SAN RAFAEL RIVER BASIN	San Rafael River Tributary Area	33,000	
(Total Area: 1670 mi.^{2})	TOTAL		33,000

Table B-2. Subbasin areas and location of irrigated acreage within the Grand Division.

Subbasin	Irrigated Acreage Within Subbasin		Total Irrigated Acreage in Subbasin
	Area	Acreage	
COLORADO RIVER ABOVE HOT SULPHUR SPRINGS, COLORADO	Intervening Acreage	9,000	
	Fraser River Tributary Area	10,500	
	Intervening Area	2,500	
(Total Area: 838 mi.^{2})	TOTAL		22,000
EAGLE RIVER BASIN	Eagle River Tributary Area	20,300	
(Total Area: 957 mi.^{2})	TOTAL		20,300
COLORADO RIVER ABOVE GLENWOOD SPRINGS, COLORADO	Intervening Area	500	
	Williams River Tributary Area	4,500	
	Intervening Area	2,000	
(Total Area: 2765 mi.^{2})	Troublesome Creek Tributary Area	8,000	
	Intervening Area	7,500	
	Blue River Tributary Area	9,200	
	Muddy Creek Tributary Area	10,500	
	Intervening Area	25,500	
	TOTAL		67,700
ROARING FORK RIVER BASIN	Roaring Fork Tributary Area	27,200	
(Total Area: 1451 mi.^{2})	TOTAL		27,200
COLORADO RIVER ABOVE PLATEAU CREEK	Intervening Area	50,400	
(Total Area: 2064 mi.^{2})	TOTAL		50,400
PLATEAU CREEK BASIN	Plateau Creek Tributary Area	20,200	
(Total Area: 604 mi.^{2})	TOTAL		20,200
GUNNISON RIVER ABOVE GUNNISON, COLORADO	Source of Taylor River	0	
	East River at Almont Tributary Area	7,700	
(Total Area: 2030 mi.^{2})	Ohio Creek Tributary Area	15,500	
	Cochetopa Creek Tributary Area	7,000	
	Tomichi Creek Tributary Area	20,400	
	TOTAL		50,600

Table B-2. Continued.

Subbasin	Irrigated Acreage Within Subbasin		Total Irrigated Acreage in Subbasin
	Area	Acreage	
GUNNISON RIVER ABOVE NORTH FORK GUNNISON RIVER (Total Area: 2258 mi.^{2})	Intervening Area	4,000	
	Cebolla Creek Tributary Area	3,400	
	Intervening Area	500	
	Lake Fork Tributary Area	3,000	
	Intervening Area	300	
	Cimarron Creek Tributary Area	3,500	
	Intervening Area	200	
	Smith Fork Tributary Area	17,800	
	TOTAL		32,700
UNCOMPAHGRE RIVER BASIN (Total Area: 1110 mi.^{2})	Uncompahgre River Tributary Area	96,000	
	TOTAL		96,000
GUNNISON RIVER ABOVE GRAND JUNCTION, COLORADO (Total Area: 2530 mi.^{2})	North Fork Gunnison River Tributary Area	25,200	
	Intervening Area	27,500	
	Roubideau Creek Tributary Area	1,500	
	Intervening Area	7,500	
	TOTAL		61,700
COLORADO RIVER ABOVE COLORADO-UTAH STATE LINE (Total Area: 1557 mi.^{2})	Grand Valley		
	North of Colorado River	68,300	
	South of Colorado River and above Gunnison River	7,500	
	South of Colorado River and below Gunnison River	3,500	
	TOTAL		79,300
SAN MIGUEL RIVER BASIN (Total Area: 1550 mi.^{2})	San Miguel above Placerville, Colorado	5,400	
	San Miguel above Naturita, Colorado	19,800	
	TOTAL		25,200
DOLORES RIVER BASIN (Total Area: 3030 mi.^{2})	Dolores River above Dolores, Colorado	4,500	
	Intervening Area	600	
	Disappointment Creek Tributary Area	1,300	
	LaSal Creek Tributary Area	2,200	
	Intervening Area	4,500	
	West Creek Tributary Area	1,000	
	Intervening Area	500	
	TOTAL		14,600
COLORADO RIVER ABOVE CISCO, UTAH (Total Area: 1356 mi.^{2})	Intervening Area	2,500	
	TOTAL		2,500

Table B-3. Subbasin areas and location or irrigated acreage within the San Juan Division.

Subbasin	Irrigated Acreage Within Subbasin		Total Irrigated Acreage in Subbasin
	Area	Acreage	
SAN JUAN RIVER ABOVE ARBOLES, COLORADO	Intervening Area	7,000	
	Navajo River basin Tributary Area	2,500	
	Intervening Area	500	
(Total Area: 1230 mi.^{2})	TOTAL		10,000
SAN JUAN RIVER ABOVE ARCHULETA, NEW MEXICO	Piedra River Tributary Area	3,500	
	Intervening Area	2,100	
(Total Area: 2030 mi.^{2})	Los Pinos River Tributary Area	49,100	
	TOTAL		54,700
ANIMAS RIVER BASIN	Animas Tributary Area above Colorado-New Mexico State Line	6,400	
(Total Area: 1360 mi.^{2})	Florida River Tributary Area	14,000	
	Intervening Area	7,800	
	TOTAL		28,200
SAN JUAN RIVER ABOVE FARMINGTON, NEW MEXICO (Total Area: 2620 mi.^{2})	Intervening Area	10,400	
	TOTAL		10,400
LA PLATA RIVER BASIN	La Plata Tributary Area at Colorado-New Mexico State Line	18,000	
(Total Area: 583 mi.)	Intervening Area	8,000	
	TOTAL		26,000
SAN JUAN RIVER ABOVE SHIPROCK, NEW MEXICO (Total Area: 5077 mi.^{2})	Intervening Area	8,800	
	Chaco River Tributary Area	3,500	
	TOTAL		12,300
SAN JUAN ABOVE BLUFF, UTAH	Intervening Area	5,000	
	Mancos River Tributary Area	13,000	
	McElmo Creek Tributary Area	35,000	
(Total Area: 10,100 mi.^{2})	Montezuma Creek Tributary Area	3,500	
	Intervening Area	500	
	Recapture Creek Tributary Area	3,000	
	Chinle Creek Tributary Area	7,500	
	TOTAL		67,500
COLORADO RIVER ABOVE LEE'S FERRY, ARIZONA (Total Area: 19,940 mi.^{2})			
	Fremont River Tributary Area	15,000	
	Muddy Creek Tributary Area	8,000	
	Castle Valley	1,000	
	Intervening Area	800	
	Mill Creek Tributary Area	3,500	
	Indian Creek Tributary Area	1,000	
	Escalante River Tributary Area	6,000	
	Paria River Basin Area	3,000	
	TOTAL		38,300

APPENDIX C

Climatological Stations and Data for Each Subbasin

Table C-1. Weighted precipitation and temperature data for irrigated lands within the subbasins of the Green Division.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
NEW FORK RIVER BASIN																
Precipitation																
Pinedale, Wyo.	(1906-50, 55-67)		1.0	0.72	0.63	0.65	0.84	1.33	1.22	0.81	1.01	1.15	0.84	0.64	0.82	10.66
		1965		0.40	0.18	0.19	0.61	1.59	3.19	1.25	1.10	2.05	0.39	1.09	0.59	12.63
		1966		0.18	0.29	0.58	0.60	1.60	1.99	0.26	0.88	1.69	0.20	0.21	0.67	9.15
Temperature																
Pinedale, Wyo.	(1906-50, 55-57)		1.0	11.52	14.99	22.05	35.45	44.28	53.06	60.24	57.20	48.85	38.82	25.70	14.90	35.59
		1965		16.30	15.20	11.50	35.40	41.90	50.60	60.10	54.60	42.30	44.00	29.60	14.10	34.60
		1966		9.60	10.40	21.40	33.20	47.10	50.90	61.80	56.60	52.00	33.40	28.90	14.30	35.00
GREEN RIVER ABOVE LABARGE, WYOMING																
Precipitation																
Big Piney, Wyo.	(1905-67)		1.0	0.38	0.30	0.42	0.82	1.36	1.05	0.75	0.86	0.99	0.82	0.45	0.42	8.62
		1965		0.17	0.15	0.31	0.63	1.15	1.61	0.52	1.53	2.03	0.29	1.24	0.85	10.48
		1966		0.01	0.16	0.37	0.40	0.40	1.14	0.53	0.50	2.45	0.30	0.20	0.68	7.14
Temperature																
Big Piney, Wyo.	(1905-67)		1.0	8.81	13.32	22.38	35.72	45.53	52.66	59.38	56.33	47.93	37.78	23.20	13.41	34.70
		1965		15.2	17.2	17.6	36.6	43.0	52.7	59.7	55.0	41.7	40.70	27.10	4.30	34.20
		1966		1.7	5.4	33.5	39.0	47.4	51.9	61.6	55.7	50.2	33.40	26.70	9.20	34.60
GREEN RIVER ABOVE FONTENELLE RESERVOIR																
Precipitation																
Fontenelle Dam, Wyo.	(1962-67)		1.0	0.16	0.31	0.17	0.69	0.87	1.35	0.48	0.55	0.97	0.39	0.28	0.54	6.76
		1965		T	0.33	0.11	1.22	1.26	2.66	0.76	0.79	1.32	0.27	0.81	0.53	10.06
		1966		0.08	0.32	0.18	0.63	0.38	0.67	0.57	0.76	0.86	0.70	0.14	0.62	5.91
Temperature																
Fontenelle Dam, Wyo.	(1962-67)		1.0	12.32	20.76	24.26	39.66	49.54	56.70	65.96	62.66	53.07	42.65	28.75	17.25	39.46
		1965		19.50	22.70	23.80	41.10	47.10	56.20	64.90	61.70	47.30	45.60	33.70	16.90	40.00
		1966		11.10	12.20	29.30	37.10	51.30	56.50	68.20	62.80	56.10	38.60	32.20	13.30	39.10
BIG SANDY CREEK BASIN																
Precipitation																
Farson, Wyo.	(1908-67)		1.0	0.38	0.45	0.43	0.66	0.96	0.90	0.61	0.62	0.68	0.66	0.36	0.33	7.04
		1962		0.36	0.73	0.05	0.24	0.85	0.35	0.27	0.24	0.27	T	0.04	0.00	3.40
		1963		0.38	0.05	0.02	0.99	0.51	1.90	0.20	1.41	1.21	0.21	0.17	0.19	7.24
Temperature																
Farson, Wyo.	(1908-67)		1.0	8.94	14.85	25.26	38.25	48.20	56.78	64.03	61.27	52.16	41.18	25.52	13.79	37.52
		1962		1.10	14.50	15.50	41.00	49.80	57.00	62.60	60.20	53.60	43.40	30.60	19.70	37.42
		1963		12.10	28.20	28.90	37.40	51.40	56.30	64.40	63.80	56.30	45.90	28.40	15.40	40.70
GREEN RIVER ABOVE GREEN RIVER, WYOMING																
Precipitation																
Green River, Wyo.	(1903-67)		1.0	0.41	0.48	0.58	0.85	1.13	0.73	0.49	0.75	0.74	0.88	0.46	0.37	7.87
		1964		0.07	0.15	0.48	1.12	1.10	1.51	0.42	0.68	0.05	0.11	0.43	1.14	7.26
		1965		0.31	0.13	0.49	0.93	2.03	2.16	1.15	0.63	0.95	0.51	0.51	0.70	10.50
Temperature																
Green River, Wyo.	(1903-67)		1.0	18.30	23.60	32.10	42.80	52.50	61.40	69.10	66.70	56.80	45.40	31.90	21.40	43.50
		1964		16.50	16.30	24.40	38.90	51.40	57.50	70.00	64.20	54.60	44.90	28.10	21.10	40.70
		1965		21.00	24.60	24.70	43.30	49.10	58.80	67.40	63.20	47.90	47.50	36.70	18.90	41.90

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Preceding page blank

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
BLACKS FORK RIVER BASIN																
Precipitation																
Fort Bridger AP, Wyo.	(1945-67)		1.0	0.62	0.54	0.70	0.83	1.08	1.21	0.76	0.97	0.75	1.06	0.74	0.56	9.82
		1964		0.21	0.29	0.05	0.87	1.60	2.42	0.04	0.27	0.00	0.17	0.35	1.45	7.72
		1965		0.26	0.47	0.20	0.55	2.00	2.99	1.76	1.12	0.84	0.55	0.41	1.08	12.23
Temperature																
Fort Bridger AP, Wyo.	(1945-67)		1.0	22.00	24.00	28.30	39.80	49.60	59.00	66.00	64.20	55.30	46.60	31.60	25.40	42.60
		1964		20.30	18.60	24.20	37.50	49.30	54.50	68.10	63.80	55.70	48.60	28.70	23.60	41.10
		1965		22.10	22.20	23.90	40.30	45.40	55.50	63.90	61.40	47.20	50.40	35.80	21.30	40.80
GREEN RIVER ABOVE FLAMING GORGE																
Precipitation																
Manila, Ut.	(1910-43, 53-67)		1.0	0.37	0.56	0.74	1.24	1.18	0.70	0.89	0.94	0.94	1.01	0.54	0.34	8.45
		1965		0.22	T	0.40	1.95	2.78	2.02	1.64	0.74	2.08	0.80	0.58	0.25	13.46
		1966		T	0.50	0.03	0.53	0.77	0.66	1.38	0.89	0.58	0.54	0.44	0.61	6.93
Temperature																
Manila, Ut.	(1911-43, 53-67)		1.0	21.60	26.20	33.10	41.60	51.50	59.90	67.50	65.30	59.00	46.90	34.00	23.30	43.40
		1965		25.70	27.30	27.80	43.50	49.10	57.50	67.10	65.40	52.10	50.60	39.80	25.30	44.30
		1966		21.40	23.40	36.50	42.20	57.00	62.00	72.30	67.80	62.50	47.60	38.20	25.80	46.40
LITTLE SNAKE RIVER BASIN																
Precipitation																
Dixon, Wyo.	(1922-67)		1.0	0.90	0.72	1.07	1.16	1.23	0.91	1.17	1.24	1.07	1.23	0.81	1.10	12.61
		1965		0.94	0.41	0.36	0.26	2.53	0.62	3.14	1.18	2.33	T	0.89	1.52	14.18
		1966		0.28	0.42	0.50	0.34	0.66	0.88	0.62	1.00	0.68	1.39	0.47	1.37	8.59
Temperature																
Dixon, Wyo.	(1922-67)		1.0	16.71	22.00	29.79	41.66	50.44	58.47	65.43	63.00	54.44	44.20	30.25	20.50	41.40
		1965		18.70	18.70	21.40	43.50	49.20	57.50	65.40	63.60	50.00	46.60	36.80	21.00	41.00
		1966		15.90	17.60	31.10	40.60	52.50	57.50	65.30	61.40	56.60	39.90	34.30	17.60	40.90
YAMPA RIVER BASIN																
Precipitation																
Yampa, Colo.	(1909-19, 22-25,41-42,47-67)		0.16	1.68	1.37	1.28	1.35	1.07	1.13	1.76	1.73	1.46	1.10	1.05	1.41	16.39
Hayden, Colo.	(1932-67)		0.17	1.32	1.20	1.31	1.54	1.49	1.12	1.26	1.45	1.53	1.43	1.07	1.42	16.14
Craig, Colo.	(1944-67)		0.17	0.90	0.81	1.03	1.31	1.37	1.18	0.92	1.34	1.19	1.23	0.88	1.07	13.23
Hamilton, Colo.	(1936-67)		0.16	1.31	1.35	1.76	1.69	1.57	1.16	1.20	1.36	1.60	1.38	1.32	1.66	17.36
Steamboat Springs, Colo.	(1908-67)		0.34	2.40	2.35	2.20	2.19	2.07	1.46	1.36	1.41	1.71	1.87	1.73	2.42	23.17
		1965		2.43	0.77	1.41	1.42	2.50	1.67	3.27	2.28	3.22	0.116	1.99	1.37	22.45
		1966		0.63	0.95	0.75	0.56	1.28	0.33	1.02	1.76	1.24	2.30	0.44	2.30	13.56
Temperature																
Hayden, Colo.	(1932-67)		0.5	16.89	21.33	29.15	40.99	51.08	59.35	66.03	64.20	55.73	45.48	31.52	20.91	41.90
Steamboat Springs, Colo.	(1908-67)		0.5	14.26	18.44	26.49	38.71	48.31	55.32	61.44	59.82	52.31	43.17	29.96	17.78	38.80
		1965		19.95	17.85	19.30	40.15	47.70	55.45	62.45	59.40	48.40	45.80	35.70	21.00	39.40
		1966		15.55	18.65	30.80	40.15	51.15	57.30	66.05	61.30	55.65	41.95	35.55	17.70	40.98

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
GREEN RIVER ABOVE JENSEN, UTAH																
Precipitation																
Dinosaur N. M., Ut.	(1941-42, 47-67)		0.4	0.58	0.40	0.71	0.84	0.72	0.75	0.39	0.86	0.39	1.08	0.61	0.88	8.21
Maybell, Colo.	(1961-67)		0.6	0.68	0.68	0.87	1.35	0.83	0.70	0.59	1.14	1.32	0.76	1.20	1.26	11.38
		1964		0.52	0.31	0.90	1.44	0.70	0.87	0.21	0.73	0.67	0.28	2.43	2.27	11.33
		1965		1.01	0.29	0.48	1.21	1.58	1.99	1.73	1.04	2.10	0.39	1.37	1.33	14.52
Temperature																
Dinosaur N. M., Ut.	(1956-67)		0.4	16.40	26.80	34.70	49.00	58.90	66.70	75.10	72.20	62.30	51.90	36.00	19.20	47.40
Maybell, Colo.	(1961-67)		0.6	14.90	23.50	28.30	43.40	52.80	60.20	56.40	53.90	54.80	45.20	33.10	19.90	40.50
		1964		16.00	18.90	26.40	44.00	54.70	60.80	72.70	66.70	58.10	47.90	27.90	19.40	42.80
		1965		17.10	19.70	25.40	47.30	52.70	60.40	68.60	65.50	51.80	47.90	39.20	23.20	43.20
ASHLEY CREEK BASIN																
Precipitation																
Vernal AP, Ut.	(1895-67)		1.0	0.57	0.51	0.70	0.84	0.76	0.51	0.55	0.73	0.96	0.90	0.61	0.59	8.23
		1964		0.06	0.06	0.76	0.79	0.48	0.98	0.19	0.50	0.38	0.17	1.33	1.94	7.64
		1965		0.58	0.12	0.39	0.54	1.29	2.27	0.93	0.76	1.73	0.42	1.11	1.03	11.17
Temperature																
Vernal AP, Ut.	(1895-67)		1.0	16.25	22.79	34.29	45.68	54.16	62.54	68.93	66.64	58.80	47.20	32.79	20.04	44.20
		1964		19.90	24.30	29.30	45.30	55.30	62.10	72.70	67.10	58.70	49.10	26.40	16.20	43.90
		1965		14.90	19.70	28.40	46.50	53.10	61.00	69.70	66.60	52.50	49.10	39.20	22.50	43.60
DUCHESNE RIVER ABOVE DUCHESNE, UTAH																
Precipitation																
Duchesne, Ut.	(1906-67)		0.67	0.55	0.58	0.72	0.65	0.75	0.76	0.95	1.21	1.04	0.94	0.52	0.58	9.25
Hanna, Ut.	(1952-67)		0.33	0.82	0.71	0.60	0.80	0.99	0.92	0.87	1.60	1.43	0.85	0.87	0.94	11.40
		1965		0.36	0.43	0.56	1.16	1.46	3.22	1.28	1.07	1.80	0.59	1.29	1.18	14.40
		1966		0.01	0.50	0.25	0.12	1.05	0.31	0.91	1.62	1.81	0.78	0.19	2.15	9.70
Temperature																
Duchesne, Ut.	(1906-67)		0.67	16.70	23.60	35.10	45.60	54.20	62.20	69.10	67.10	58.40	47.00	32.70	20.90	44.40
Hanna, Ut.	(1953-67)		0.33	21.10	25.10	29.76	40.20	49.60	57.70	64.80	62.60	55.10	46.40	32.40	24.30	42.40
		1965		21.60	24.20	30.00	44.60	50.50	58.60	68.10	64.70	51.20	50.10	38.70	22.50	42.90
		1966		17.30	21.40	36.00	45.30	56.10	61.80	70.10	66.60	60.00	45.70	36.80	13.30	44.20
DUCHESNE RIVER ABOVE RANDLETT, UTAH																
Precipitation																
Altamont, Ut.	(1923-37, 49-67)		0.25	0.44	0.42	0.46	0.61	0.77	0.49	0.64	1.01	0.88	0.90	0.53	0.62	7.77
Myton, Ut.	(1916-67)		0.25	0.34	0.31	0.43	0.55	0.59	0.48	0.66	0.87	0.83	0.75	0.44	0.45	6.70
Neola, Ut.	(1956-67)		0.17	0.42	0.49	0.35	0.57	1.14	0.77	0.55	0.83	0.94	0.69	0.77	0.83	8.35
Roosevelt, Ut.	(1940-67)		0.16	0.58	0.41	0.58	0.65	0.58	0.75	0.41	0.88	0.79	0.94	0.50	0.63	7.70
Ft. Duchesne, Ut.	(1888-67)		0.17	0.45	0.39	0.54	0.60	0.68	0.52	0.50	0.68	0.95	0.75	0.42	0.50	6.98
		1964		0.02	0.21	0.68	1.00	1.28	0.60	0.38	0.58	0.42	T	1.67	1.98	8.82
		1965		0.53	0.37	0.50	0.65	1.90	3.14	1.34	1.04	1.48	0.60	0.90	1.14	13.59

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
BLACKS FORK RIVER BASIN																
Precipitation																
Fort Bridger AP, Wyo.	(1945-67)		1.0	0.62	0.54	0.70	0.83	1.08	1.21	0.76	0.97	0.75	1.06	0.74	0.56	9.82
		1964		0.21	0.29	0.05	0.87	1.60	2.42	0.04	0.27	0.00	0.17	0.35	1.45	7.72
		1965		0.26	0.47	0.20	0.55	2.00	2.99	1.76	1.12	0.84	0.55	0.41	1.08	12.23
Temperature																
Fort Bridger AP, Wyo.	(1945-67)		1.0	22.00	24.00	28.30	39.80	49.60	59.00	66.00	64.20	55.30	46.60	31.60	25.40	42.60
		1964		20.30	18.60	24.20	37.50	49.30	54.50	68.10	63.80	55.70	48.60	28.70	23.60	41.10
		1965		22.10	22.20	23.90	40.30	45.40	55.50	63.90	61.40	47.20	50.40	35.80	21.30	40.80
GREEN RIVER ABOVE FLAMING GORGE																
Precipitation																
Manila, Ut.	(1910-43, 53-67)		1.0	0.37	0.56	0.74	1.24	1.18	0.70	0.89	0.94	0.94	1.01	0.54	0.34	8.45
		1965		0.22	T	0.40	1.95	2.78	2.02	1.64	0.74	2.08	0.80	0.58	0.25	13.46
		1966		T	0.50	0.03	0.53	0.77	0.66	1.38	0.89	0.58	0.54	0.44	0.61	6.93
Temperature																
Manila, Ut.	(1911-43, 53-67)		1.0	21.60	26.20	33.10	41.60	51.50	59.90	67.50	65.30	59.00	46.90	34.00	23.30	43.40
		1965		25.70	27.30	27.80	43.50	49.10	57.50	67.10	65.40	52.10	50.60	39.80	25.30	44.30
		1966		21.40	23.40	36.50	42.20	57.00	62.00	72.30	67.80	62.50	47.60	38.20	25.80	46.40
LITTLE SNAKE RIVER BASIN																
Precipitation																
Dixon, Wyo.	(1922-67)		1.0	0.90	0.72	1.07	1.16	1.23	0.91	1.17	1.24	1.07	1.23	0.81	1.10	12.61
		1965		0.94	0.41	0.36	0.26	2.53	0.62	3.14	1.18	2.33	T	0.89	1.52	14.18
		1966		0.28	0.42	0.50	0.34	0.66	0.88	0.62	1.00	0.68	1.39	0.47	1.37	8.59
Temperature																
Dixon, Wyo.	(1922-67)		1.0	16.71	22.00	29.79	41.66	50.44	58.47	65.43	63.00	54.44	44.20	30.25	20.50	41.40
		1965		18.70	18.70	21.40	43.50	49.20	57.50	65.40	63.60	50.00	46.60	36.80	21.00	41.00
		1966		15.90	17.60	31.10	40.60	52.50	57.50	66.30	61.40	56.60	39.90	34.30	17.60	40.90
YAMPA RIVER BASIN																
Precipitation																
Yampa, Colo.	(1909-19, 22-25,41-42,47-67)		0.16	1.68	1.37	1.28	1.35	1.07	1.13	1.76	1.73	1.46	1.10	1.05	1.41	16.39
Hayden, Colo.	(1932-67)		0.17	1.32	1.20	1.31	1.54	1.49	1.12	1.26	1.45	1.53	1.43	1.07	1.42	16.14
Craig, Colo.	(1944-67)		0.17	0.90	0.81	1.03	1.31	1.37	1.18	0.92	1.34	1.19	1.23	0.88	1.07	13.23
Hamilton, Colo.	(1936-67)		0.16	1.31	1.35	1.76	1.69	1.57	1.16	1.20	1.36	1.60	1.38	1.32	1.66	17.36
Steamboat Springs, Colo.	(1908-67)		0.34	2.40	2.35	2.20	2.19	2.07	1.46	1.36	1.41	1.71	1.87	1.73	2.42	23.17
		1965		2.43	0.77	1.41	1.42	2.50	1.67	3.27	2.28	3.22	0.116	1.99	1.37	22.45
		1966		0.63	0.95	0.75	0.56	1.28	0.33	1.02	1.76	1.24	2.30	0.44	2.30	13.56
Temperature																
Hayden, Colo.	(1932-67)		0.5	16.89	21.33	29.15	40.99	51.08	59.35	66.03	64.20	55.73	45.48	31.52	20.91	41.90
Steamboat Springs, Colo.	(1908-67)		0.5	14.26	18.44	26.49	38.71	48.31	55.32	61.44	59.82	52.31	43.17	29.96	17.78	38.80
		1965		19.95	17.85	19.30	40.15	47.70	55.45	62.45	59.40	48.40	45.80	35.70	21.00	39.40
		1966		15.55	18.65	30.80	40.15	51.15	57.30	66.05	61.30	55.65	41.95	35.55	17.70	40.98

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
GREEN RIVER ABOVE JENSEN, UTAH																
Precipitation																
Dinosaur N. M., Ut.	(1941-42, 47-67)		0.4	0.58	0.40	0.71	0.84	0.72	0.75	0.39	0.86	0.39	1.08	0.61	0.88	8.21
Maybell, Colo.	(1961-67)		0.6	0.68	0.68	0.87	1.35	0.83	0.70	0.59	1.14	1.32	0.76	1.20	1.26	11.38
		1964		0.52	0.31	0.90	1.44	0.70	0.87	0.21	0.73	0.67	0.28	2.43	2.27	11.33
		1965		1.01	0.29	0.48	1.21	1.58	1.99	1.73	1.04	2.10	0.39	1.37	1.33	14.52
Temperature																
Dinosaur N. M., Ut.	(1956-67)		0.4	16.40	26.80	34.70	49.00	58.90	66.70	75.10	72.20	62.30	51.90	36.00	19.20	47.40
Maybell, Colo.	(1961-67)		0.6	14.90	23.50	28.30	43.40	52.80	60.20	56.40	53.90	54.80	45.20	33.10	19.90	40.50
		1964		16.00	18.90	26.40	44.00	54.70	60.80	72.70	66.70	58.10	47.90	27.90	19.40	42.80
		1965		17.10	19.70	25.40	47.30	52.70	60.40	68.60	65.50	51.80	47.90	39.20	23.20	43.20
ASHLEY CREEK BASIN																
Precipitation																
Vernal AP, Ut.	(1895-67)		1.0	0.57	0.51	0.70	0.84	0.76	0.51	0.55	0.73	0.96	0.90	0.61	0.59	8.23
		1964		0.06	0.06	0.76	0.79	0.48	0.98	0.19	0.50	0.38	0.17	1.33	1.94	7.64
		1965		0.58	0.12	0.39	0.54	1.29	2.27	0.93	0.76	1.73	0.42	1.11	1.03	11.17
Temperature																
Vernal AP, Ut.	(1895-67)		1.0	16.25	22.79	34.29	45.68	54.16	62.54	68.93	66.64	58.80	47.20	32.79	20.04	44.20
		1964		19.90	24.30	29.30	45.30	55.30	62.10	72.70	67.10	58.70	49.10	26.40	16.20	43.90
		1965		14.90	19.70	28.40	46.50	53.10	61.00	69.70	66.60	52.50	49.10	39.20	22.50	43.60
DUCHESNE RIVER ABOVE DUCHESNE, UTAH																
Precipitation																
Duchesne, Ut.	(1906-67)		0.67	0.55	0.58	0.72	0.65	0.75	0.76	0.95	1.21	1.04	0.94	0.52	0.58	9.25
Hanna, Ut.	(1952-67)		0.33	0.82	0.71	0.60	0.80	0.99	0.92	0.87	1.60	1.43	0.85	0.87	0.94	11.40
		1965		0.36	0.43	0.56	1.16	1.46	3.22	1.28	1.07	1.80	0.59	1.29	1.18	14.40
		1966		0.01	0.50	0.25	0.12	1.05	0.31	0.91	1.62	1.81	0.78	0.19	2.15	9.70
Temperature																
Duchesne, Ut.	(1906-67)		0.67	16.70	23.60	35.10	45.60	54.20	62.20	69.10	67.10	58.40	47.00	32.70	20.90	44.40
Hanna, Ut.	(1953-67)		0.33	21.10	25.10	29.76	40.20	49.60	57.70	64.80	62.60	55.10	46.40	32.40	24.30	42.40
		1965		21.60	24.20	30.00	44.60	50.50	58.60	68.10	64.70	51.20	50.10	38.70	22.50	42.90
		1966		17.30	21.40	36.00	45.30	56.10	61.80	70.10	66.60	60.00	45.70	36.80	13.30	44.20
DUCHESNE RIVER ABOVE RANDLETT, UTAH																
Precipitation																
Altamont, Ut.	(1923-37, 49-67)		0.25	0.44	0.42	0.46	0.61	0.77	0.49	0.64	1.01	0.88	0.90	0.53	0.62	7.77
Myton, Ut.	(1916-67)		0.25	0.34	0.31	0.43	0.55	0.59	0.48	0.66	0.87	0.83	0.75	0.44	0.45	6.70
Neola, Ut.	(1956-67)		0.17	0.42	0.49	0.35	0.57	1.14	0.77	0.55	0.83	0.94	0.69	0.77	0.83	8.35
Roosevelt, Ut.	(1940-67)		0.16	0.58	0.41	0.58	0.65	0.58	0.75	0.41	0.88	0.79	0.94	0.50	0.63	7.70
Ft. Duchesne, Ut.	(1888-67)		0.17	0.45	0.39	0.54	0.60	0.68	0.52	0.50	0.68	0.95	0.75	0.42	0.50	6.98
		1964		0.02	0.21	0.68	1.00	1.28	0.60	0.38	0.58	0.42	T	1.67	1.98	8.82
		1965		0.53	0.37	0.50	0.65	1.90	3.14	1.34	1.04	1.48	0.60	0.90	1.14	13.59

---

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Anual
Temperature																
Altamont, Ut.	(1923-37, 48-67)		0.25	17.60	24.60	33.30	44.40	55.20	62.00	70.60	68.00	57.70	47.10	33.00	21.70	44.60
Myton, Ut.	(1918-67)		0.25	16.80	27.80	34.40	47.80	56.70	66.70	74.20	71.70	61.40	51.90	33.20	20.30	46.90
Neola, Ut.	(1956-67)		0.17	17.30	25.80	31.60	44.10	54.10	61.00	69.30	66.20	56.90	48.60	33.30	21.10	44.10
Roosevelt, Ut.	(1940-67)		0.16	17.30	24.20	36.10	48.10	57.10	65.10	72.50	69.90	60.90	51.80	34.10	23.40	46.70
Ft. Duchesne, Ut.	(1888-67)		0.17	13.50	21.00	35.10	46.90	55.60	64.20	70.80	68.70	60.00	47.20	33.00	19.70	44.60
		1964		20.90	24.60	29.90	44.60	55.40	61.70	72.90	67.40	58.90	50.00	25.90	16.20	44.00
		1965		14.60	20.30	29.90	46.60	52.50	60.20	69.30	66.50	52.80	50.50	40.60	23.40	43.90
WHITE RIVER BASIN																
Precipitation																
Meeker, Colo.	(1900-67)		0.5	1.10	1.00	1.46	1.56	1.43	1.07	1.44	1.80	1.50	1.41	1.11	1.13	16.10
Little Hill, Colo.	(1946-67)		0.5	0.78	0.89	1.09	1.28	1.17	0.91	1.01	1.59	1.10	0.99	0.93	0.92	12.66
		1964		0.66	0.56	1.34	2.72	1.63	2.07	0.79	2.08	0.59	0.22	1.50	2.20	16.36
		1965		1.01	0.89	0.77	1.14	2.94	1.98	2.24	0.90	2.00	0.30	1.32	2.99	18.48
Temperature																
Meeker, Colo.	(1900-67)		0.5	20.74	24.66	33.09	43.38	51.70	59.05	65.86	64.03	56.03	45.98	33.45	22.95	43.40
Little Hill, Colo.	(1946-67)		0.5	22.63	24.64	31.16	41.67	50.72	58.04	65.47	63.12	55.66	42.50	32.06	23.75	42.70
		1964		18.10	19.30	26.30	40.90	51.90	58.50	68.80	62.70	55.50	47.90	31.00	25.30	42.20
		1965		25.40	24.30	27.10	42.90	50.40	57.30	65.30	62.20	50.50	48.70	38.10	25.50	43.10
GREEN RIVER ABOVE OURAY, UTAH																
Precipitation																
Jensen, Ut.	(1916-27, 30-67)		1.0	0.51	0.44	0.54	0.90	0.68	0.66	0.48	0.73	0.87	0.90	0.45	0.63	7.79
		1964		0.05	0.11	0.77	0.09	0.27	1.19	0.19	0.42	0.47	0.27	1.35	1.83	8.01
		1965		0.36	0.09	0.28	0.88	1.02	1.97	1.39	0.52	2.55	0.61	0.98	1.27	11.92
Temperature																
Jensen, Ut.	(1921-24, 40-67)		1.0	15.20	22.40	36.60	49.50	59.50	67.40	75.10	69.70	63.00	50.80	34.60	23.00	47.20
		1964		20.20	25.00	31.50	46.40	56.50	64.10	74.90	68.20	59.40	50.10	26.80	15.20	44.90
		1965		13.70	18.10	28.50	47.60	54.40	61.90	70.80	67.00	53.30	49.20	40.00	22.70	43.90
PRICE RIVER BASIN																
Precipitation																
Price, Ut.	(1911-67)		0.50	0.75	0.72	0.73	0.67	0.69	0.74	0.96	1.28	1.13	0.97	0.58	0.83	10.05
Castle Dale, Ut.	(1898-43, 49-67)		0.50	0.64	0.61	0.53	0.54	0.58	0.47	0.87	1.16	0.97	0.85	0.54	0.58	8.36
		1964		0.06	0.03	0.68	0.82	2.04	0.67	0.75	0.72	0.28	0.00	0.72	1.53	8.30
		1965		0.20	1.15	0.93	1.32	1.08	2.65	2.13	1.34	1.07	0.28	1.67	1.86	15.68
Temperature																
Price, Ut.	(1911-67)		1.0	22.85	30.03	38.65	48.30	57.54	66.64	73.24	71.04	62.65	51.83	37.04	26.98	48.90
		1964		23.30	27.50	30.40	45.00	55.10	63.20	74.30	68.90	60.80	53.40	32.60	23.90	46.50
		1965		31.50	31.10	37.10	46.00	53.20	62.00	69.90	68.50	54.80	53.60	41.40	26.90	48.00

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-1. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
GREEN RIVER ABOVE GREEN RIVER, UTAH																
Precipitation																
Green River, Ut.	(1898-67)		1.0	0.33	0.31	0.34	0.41	0.53	0.29	0.42	0.90	0.73	0.78	0.43	0.46	5.93
		1964		0.01	0.01	0.64	1.18	0.68	0.21	0.24	0.54	0.31	T	0.16	0.52	4.50
		1965		0.58	0.44	0.63	0.70	1.29	0.82	1.17	1.57	0.71	0.86	0.81	1.28	10.86
Temperature																
Green River, Ut.	(1900-67)		1.0	23.97	33.53	41.43	52.48	61.71	70.28	77.57	74.88	65.90	53.76	37.88	27.72	51.80
		1964		23.90	29.30	38.40	50.80	60.40	68.70	80.00	74.60	64.40	54.70	35.50	27.60	50.70
		1965		35.50	33.80	39.90	51.20	58.80	67.00	76.60	74.20	60.10	54.40	44.80	29.20	52.00
SAN RAFAEL RIVER BASIN																
Precipitation																
Castle Dale, Ut.	(1898-43, 49-67)		1.0	0.64	0.61	0.53	0.54	0.58	0.49	0.87	1.16	0.97	0.85	0.54	0.58	8.36
		1964		0.00	0.00	0.31	0.59	1.88	0.58	0.52	0.18	0.24	0.00	0.75	0.76	5.81
		1965		0.08	1.16	0.59	1.32	1.32	2.01	2.47	1.43	1.14	0.23	1.28	1.25	14.28
Temperature																
Castle Dale, Ut.	(1899-43, 56-67)		1.0	24.70	30.20	37.10	47.90	56.10	65.70	71.50	69.00	60.30	51.00	35.70	27.30	48.00
		1964		23.10	26.90	33.70	46.20	55.10	63.50	74.00	69.00	59.70	52.60	31.50	26.90	46.90
		1965		30.60	28.20	36.10	46.70	53.40	60.90	70.10	68.30	55.50	53.10	41.00	27.10	47.60

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-2. Weighted precipitation and temperature data for irrigated lands within the subbasins of the Grand Division.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
COLORADO RIVER ABOVE HOT SULPHUR SPRINGS, COLORADO																
Precipitation																
Hot Sulphur Springs, Colo.	(1954-67)		0.50	0.84	0.71	0.95	0.98	1.22	1.18	1.42	1.28	1.50	0.80	0.72	0.85	12.45
Frazier, Colo.	(1914-67)		0.25	1.56	1.54	1.70	1.97	1.73	1.43	2.00	1.69	1.44	1.20	1.18	1.34	18.78
Grand Lake, Colo.	(1939-67)		0.25	1.11	0.78	1.14	1.08	1.28	1.21	1.51	1.70	1.31	0.65	0.87	1.31	13.95
		1965		1.74	0.40	1.70	0.80	1.47	1.83	3.58	1.52	2.03	0.04	1.76	0.74	17.61
		1966		0.32	0.50	0.43	1.03	0.83	0.83	1.15	1.05	1.16	1.42	0.43	1.78	10.93
Temperature																
Hot Sulphur Springs, Colo.	(1955-67)		0.50	13.50	18.20	24.10	37.00	47.30	55.10	61.40	59.50	51.70	42.20	28.60	16.20	37.90
Frazier, Colo.	(1914-67)		0.25	11.20	14.90	20.70	31.60	40.90	48.70	54.00	52.10	45.30	35.70	22.90	13.70	32.60
Grand Lake, Colo.	(1939-67)		0.25	13.00	15.90	22.40	33.90	44.10	52.40	58.00	56.30	50.10	40.60	27.90	17.40	36.00
		1965		14.20	14.00	14.00	34.70	43.40	50.50	57.70	54.30	45.10	41.70	30.00	16.20	34.70
		1966		11.10	12.70	26.30	35.50	47.50	56.60	60.90	56.50	50.10	38.50	30.10	8.60	36.20
EAGLE RIVER BASIN																
Precipitation																
Eagle FAA AP, Colo.	(1904-11, 42-67)		1.0	0.95	0.67	0.92	1.01	0.99	0.84	0.99	1.24	1.11	0.82	0.69	0.84	11.07
		1965		0.73	0.56	1.21	0.20	0.34	0.29	1.80	0.76	3.15	T	1.40	0.38	10.82
		1966		0.28	0.37	0.09	0.22	0.62	1.11	0.19	0.92	0.26	1.00	0.66	2.41	8.13
Temperature																
Eagle FAA AP, Colo.	(1904-11, 42-67)		1.0	18.40	23.50	32.10	41.70	50.30	56.60	63.30	63.00	55.30	44.90	31.90	19.70	41.70
		1965		22.80	25.30	27.80	41.90	49.40	57.80	65.20	61.80	51.40	47.20	34.80	22.40	42.30
		1966		17.30	18.90	34.70	41.30	52.60	59.40	69.00	63.80	57.10	43.20	36.20	13.10	42.20
COLORADO RIVER ABOVE GREENWOOD SPRINGS, COLORADO																
Precipitation																
Gore Pass Ranch, Colo.	(1964-67)		0.5	0.85	0.98	0.76	1.02	0.74	1.12	0.80	2.02	1.70	0.39	0.26	0.61	11.25
Green Mt. Dam, Colo.	(1940-67)		0.25	1.19	1.01	1.50	1.65	1.62	1.21	1.42	1.58	1.22	0.95	1.04	1.00	15.39
Bond, Colo.	(1961-67)		0.25	0.48	0.46	0.61	1.17	0.95	1.28	1.40	1.88	1.90	0.46	0.66	1.48	12.73
		1965		1.17	0.52	1.67	0.46	1.26	1.01	2.29	1.76	3.07	0.07	1.16	0.90	15.34
		1966		0.16	0.44	0.24	0.96	1.07	0.45	1.16	1.16	0.88	1.27	0.56	1.87	10.22
Temperature																
Gore Pass Ranch, Colo.	(1964-67)		0.5	5.30	22.80	25.70	38.40	47.60	54.30	59.10	57.50	47.10	42.50	29.30	17.20	37.20
Green Mt. Dam, Colo.	(1940-67)		0.25	17.10	21.40	27.60	39.40	48.70	56.70	62.40	60.60	54.20	44.50	30.40	20.90	40.30
Bond, Colo.	(1961-67)		0.25	18.15	26.00	31.10	43.90	53.10	60.50	67.20	63.50	55.30	47.60	34.70	21.30	43.50
		1965		22.40	21.90	23.70	41.30	49.40	57.80	64.00	60.20	50.80	47.50	36.30	23.40	41.60
		1966		18.60	20.70	33.60	41.70	52.00	58.60	67.70	63.10	57.10	43.90	36.20	13.80	42.30
ROARING FORK BASIN																
Precipitation																
Glenwood, Colo.	(1902-67)		0.5	1.50	1.36	1.47	1.58	1.29	1.00	1.31	1.66	1.41	1.27	1.07	1.31	16.23
Aspen, Colo.	(1926-67)		0.5	1.74	1.72	1.89	1.76	1.56	1.09	1.46	1.70	1.51	1.45	1.42	1.58	18.88
		1964		1.07	0.74	1.82	2.02	1.42	1.72	1.15	3.17	1.14	0.39	2.25	2.91	19.84
		1965		1.56	0.77	3.31	0.72	1.12	1.20	2.57	1.47	2.71	0.11	1.67	1.88	19.17
Temperature																
Glenwood, Colo.	(1906-67)		0.5	23.70	28.90	37.20	46.50	55.10	63.00	69.20	67.50	60.00	49.60	36.30	25.80	46.90
Aspen, Colo.	(1930-67)		0.5	19.70	22.70	28.60	39.10	47.90	55.70	61.90	60.10	53.70	44.30	30.80	22.60	40.60
		1964		17.60	20.60	26.70	41.00	51.80	68.40	69.70	62.40	54.90	48.20	31.80	22.80	42.20
		1965		25.30	25.00	28.50	41.30	49.10	58.80	66.00	63.30	52.20	48.30	36.20	26.50	43.40

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-2. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
COLORADO RIVER ABOVE PLATEAU CREEK																
Precipitation																
Rifle, Colo.	(1910-37, 43-67)		0.75	0.90	0.69	0.91	0.99	0.92	0.61	0.99	1.16	1.05	1.14	0.78	0.87	11.01
Altenburn, Colo.	(1942-67)		0.25	1.56	1.32	1.33	1.32	1.22	0.95	1.11	1.94	1.35	1.19	1.22	1.60	16.11
		1959		0.71	1.67	0.43	1.52	0.41	1.14	0.21	2.48	1.62	1.57	0.18	0.93	12.87
		1960		0.76	1.40	1.30	0.75	0.53	0.28	0.10	0.60	0.65	0.65	0.79	0.63	8.44
Temperature																
Rifle, Colo.	(1905-67)		1.0	23.10	29.20	37.70	47.80	56.10	64.50	70.90	68.80	60.50	49.40	36.70	26.00	47.60
		1959		25.90	30.30	38.10	47.10	56.50	65.60	67.30	65.40	56.00	46.40	34.70	27.90	46.80
		1960		23.10	25.10	38.40	47.20	53.00	63.10	68.70	66.90	61.60	47.80	35.90	25.10	46.30
PLATEAU CREEK BASIN																
Precipitation																
Collbran, Colo.	(1892-67)		1.0	1.13	1.13	1.48	1.52	1.36	0.77	1.14	1.48	1.51	1.39	1.05	1.06	15.02
		1963		1.00	0.71	1.79	0.29	0.23	0.86	1.80	2.61	1.78	2.31	1.75	0.32	15.45
		1964		0.54	0.56	0.86	1.62	2.17	0.50	0.66	2.20	1.42	T	1.52	1.06	13.01
Temperature																
Collbran, Colo.	(1903-67)		1.0	22.60	28.20	36.10	46.10	54.40	62.90	69.10	67.20	59.30	48.40	35.40	25.10	46.20
		1963		18.10	36.00	37.30	47.50	60.50	64.70	73.80	69.10	65.30	57.50	40.80	27.70	49.80
		1964		23.00	23.80	30.80	45.50	56.00	63.00	74.30	68.10	61.90	54.60	35.60	26.10	46.90
GUNNISON RIVER ABOVE GUNNISON, COLORADO																
Precipitation																
Gunnison, Colo.	(1895-67)		0.5	0.84	0.82	0.76	0.75	0.80	0.70	1.50	1.41	0.87	0.67	0.61	0.71	10.44
Cochetopa Creek, Colo.	(1909-16, 47-67)		0.3	0.83	0.77	0.67	0.76	0.90	0.72	1.45	1.58	0.68	0.63	0.59	0.73	10.31
Crested Butte, Colo.	(1894-04, 06-67)		0.2	2.65	2.34	2.45	1.76	1.42	1.38	2.01	2.15	1.99	1.33	1.53	2.24	23.25
		1964		0.71	1.55	1.73	0.75	1.16	0.68	2.00	1.82	1.22	0.12	1.28	1.83	13.85
		1965		1.16	0.73	1.82	0.76	0.67	1.03	3.48	1.87	1.67	0.43	2.11	0.98	16.71
Temperature																
Gunnison, Colo.	(1900-67)		0.5	8.70	14.00	25.50	39.40	48.00	56.80	61.70	60.00	52.60	41.80	28.00	13.40	33.90
Cochetopa Creek, Colo.	(1909-16, 47-67)		0.3	10.00	13.90	23.40	37.30	46.90	55.40	61.20	59.20	52.30	41.90	26.80	14.00	36.90
Crested Butte, Colo.	(1909-67)		0.2	12.80	16.00	22.80	33.10	43.90	52.10	57.60	56.20	48.70	38.40	25.00	17.60	35.30
		1964		5.50	8.30	12.60	34.50	45.80	53.00	62.40	56.80	49.70	42.20	28.20	14.50	30.50
		1965		13.00	11.90	20.80	37.50	44.90	52.90	60.20	56.70	48.40	42.40	29.60	11.60	35.80
GUNNISON RIVER ABOVE NORTH FORK GUNNISON RIVER																
Precipitation																
Cimarron, Colo.	(1951-67)		1.0	1.80	1.14	1.22	0.78	1.05	0.83	1.09	1.76	1.37	0.84	0.73	1.12	13.73
		1964		1.18	0.60	1.72	0.88	0.69	0.50	1.14	2.03	0.91	0.01	0.35	0.91	10.92
		1965		1.98	0.68	1.70	1.19	2.04	1.02	3.14	1.81	2.87	1.25	2.02	0.37	20.07
Temperature																
Cimarron, Colo.	(1951-67)		1.0	16.60	21.10	30.10	41.60	50.40	59.30	64.90	62.70	54.80	41.40	32.40	18.60	41.20
		1964		11.60	14.90	22.80	38.70	51.70	55.00	65.20	59.70	52.50	46.00	30.90	21.20	39.20
		1965		19.30	20.40	28.30	42.10	47.60	55.50	62.50	61.20	52.00	46.50	35.40	21.40	41.00

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-2. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
UNCOMPAHORE RIVER BASIN																
Precipitation																
Montrose, Colo.	(1885-67)		1.0	0.62	0.57	0.73	0.94	0.83	0.45	0.83	1.31	1.00	0.97	0.58	0.67	9.50
		1960		1.94	0.93	1.29	0.80	0.41	0.36	0.34	0.67	0.31	0.73	0.23	1.42	9.43
		1961		0.15	0.89	1.66	0.94	0.78	0.07	0.22	1.26	2.84	1.40	0.35	0.73	11.29
Temperature																
Montrose, Colo.	(1885-67)		1.0	24.80	31.40	39.20	48.10	57.70	66.30	71.90	70.40	61.80	50.30	37.00	27.20	48.80
		1960		22.10	24.00	38.30	48.50	56.50	68.10	74.00	72.00	65.20	50.30	39.40	25.30	48.60
		1961		25.10	33.00	39.50	47.00	58.50	69.30	71.90	71.30	56.30	49.20	35.70	23.00	48.30
GUNNISON RIVER ABOVE GRAND JUNCTION, COLORADO																
Precipitation																
Paonia, Colo.	(1892-67)		0.4	1.32	1.25	1.38	1.48	1.29	0.67	0.99	1.29	1.30	1.42	1.06	1.24	14.69
Delta 1 E, Colo.	(1888-67)		0.4	0.54	0.47	0.60	0.64	0.74	0.42	0.70	1.06	0.94	0.85	0.51	0.51	7.98
Cedaredge, Colo.	(1906-67)		0.2	0.86	0.96	1.06	1.06	1.06	0.69	0.90	1.23	1.22	1.15	0.73	0.83	11.75
		1965		0.96	0.76	1.31	1.10	1.27	1.17	1.38	1.42	2.63	0.84	1.85	1.06	15.75
		1966		0.21	0.53	0.13	0.79	1.17	0.47	0.30	0.78	0.63	0.61	1.23	2.05	8.90
Temperature																
Paonia, Colo.	(1892-67)		0.4	26.20	31.30	38.40	47.80	57.30	65.90	71.90	70.20	62.50	52.70	38.60	29.70	49.40
Delta 1 E, Colo.	(1888-67)		0.4	25.20	32.50	41.60	51.10	59.90	68.40	74.30	71.60	63.60	51.80	37.80	26.90	50.40
Cedaredge, Colo.	(1906-67)		0.2	26.60	31.20	38.70	47.80	56.40	64.90	71.10	69.30	61.20	50.60	37.80	28.80	48.70
		1965		31.48	31.58	36.30	47.96	55.38	63.40	71.16	68.68	58.16	52.16	42.70	33.00	49.32
		1966		25.64	28.76	41.74	49.08	60.64	66.84	74.66	70.90	63.80	50.78	42.64	28.54	50.34
COLORADO RIVER ABOVE UTAH-COLORADO STATE LINE																
Precipitation																
Grand Junction, Colo.	(1946-67)		0.5	0.69	0.61	0.69	0.74	0.64	0.40	0.43	1.12	0.82	0.78	0.66	0.59	8.17
Fruita, Colo.	(1902-67)		0.5	0.79	0.69	0.87	0.75	0.68	0.43	0.71	1.05	1.05	0.93	0.66	0.71	9.32
		1964		0.55	0.02	0.66	1.25	0.42	0.18	0.57	1.45	0.54	T	1.09	0.65	7.38
		1965		0.75	0.83	0.95	1.81	1.15	1.01	0.97	0.75	2.04	1.13	0.87	0.76	13.38
Temperature																
Grand Junction, Colo.	(1946-67)		0.5	26.40	32.60	41.20	52.30	62.20	71.80	78.50	75.00	67.30	55.40	39.50	29.40	52.60
Fruita, Colo.	(1902-67)		0.5	23.80	31.60	41.60	50.90	60.00	68.80	75.30	72.80	63.90	52.00	37.90	26.80	50.40
		1964		23.60	28.40	36.30	49.70	61.10	69.40	79.30	72.70	64.70	55.60	37.20	30.20	50.70
		1965		31.90	32.70	39.50	51.50	60.10	67.60	76.20	68.80	61.10	55.50	46.00	32.70	52.00
SAN MIQUEL RIVER BASIN																
Precipitation																
Norwood, Colo.	(1924-67)		1.0	1.03	1.15	1.22	1.34	0.97	0.79	1.66	2.14	1.51	1.43	0.92	1.06	15.22
		1964		0.43	0.49	1.08	1.23	0.59	0.48	2.04	2.14	1.46	0.00	1.37	1.47	12.78
		1965		1.77	0.82	1.82	1.58	1.30	0.84	2.65	2.52	3.16	1.39	1.23	1.78	20.86
Temperature																
Norwood, Colo.	(1924-67)		1.0	23.10	26.20	32.80	43.10	52.20	61.20	66.60	64.50	57.20	47.20	33.00	24.70	44.30
		1964		19.20	20.30	28.90	40.30	52.70	58.90	68.50	62.30	56.20	49.80	29.50	24.50	42.60
		1965		24.60	24.80	30.30	42.70	48.60	57.60	65.50	63.30	52.30	47.80	37.90	28.00	43.60

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-2. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
DOLORES RIVER BASIN																
Precipitation																
Paradox, Colo.	(1941-67)		0.199	0.52	0.50	0.38	0.51	0.44	0.37	0.66	1.00	0.54	0.73	0.48	0.57	6.70
Dolores, Colo.	(1908-28, 47-67)		0.296	1.55	1.46	1.76	1.83	1.17	0.79	1.45	2.05	1.57	1.63	1.35	1.89	18.50
Northdale, Colo.	(1930-67)		0.193	0.94	0.93	0.98	1.08	0.89	0.55	1.21	1.54	1.54	1.49	0.95	1.19	13.29
Uravan, Colo.	(1961-67)		0.113	0.84	0.68	0.87	1.35	1.15	0.43	1.19	1.45	1.39	0.99	1.23	1.64	13.21
Gateway, Colo.	(1947-67)		0.119	0.80	0.72	0.76	1.01	0.90	0.52	0.98	1.43	0.90	1.27	0.78	0.80	10.87
		1964		0.42	0.07	1.37	1.78	0.72	0.21	1.86	1.96	1.70	0.00	1.61	1.39	13.09
		1965		1.48	1.18	1.27	2.42	1.77	1.31	2.25	1.62	2.36	2.27	2.23	2.90	23.06
Temperature																
Paradox, Colo.	(1941-67)		0.22	27.40	33.40	39.10	48.90	57.50	66.80	73.50	70.90	63.30	52.40	38.00	29.50	50.10
Northdale, Colo.	(1931-67)		0.13	22.30	27.00	34.00	43.80	52.00	60.60	68.10	66.20	58.30	47.30	34.00	25.70	44.90
Uravan, Colo.	(1961-67)		0.22	27.00	35.40	39.80	51.90	58.80	69.40	77.10	74.60	65.10	55.60	41.60	29.50	52.20
Gateway, Colo.	(1961-67)		0.11	28.10	37.00	43.00	52.90	62.10	70.10	77.20	75.10	66.00	54.90	43.90	32.40	53.60
Yellowjacket, Colo.	(1962-67)		0.32	22.60	27.20	34.60	42.40	53.30	61.30	70.50	67.10	60.00	51.70	39.10	25.60	46.50
		1964		24.80	26.70	33.80	45.60	57.10	64.70	74.70	69.00	61.50	53.80	34.70	28.70	47.93
		1965		30.50	30.40	35.90	46.70	53.80	61.80	71.80	69.30	57.90	52.80	42.70	31.30	48.74
COLORADO RIVER ABOVE CISCO, UTAH																
Precipitation																
Cisco, Utah	(1892-05, 53-67)		1.0	0.51	0.54	0.60	0.67	0.55	0.21	0.39	1.04	0.83	0.89	0.64	0.37	7.24
		1964		0.40	0.00	0.29	0.85	0.41	0.05	0.82	0.71	0.67	0.00	0.57	0.30	5.07
		1965		0.34	0.18	0.64	1.78	1.25	1.47	1.72	0.74	0.81	1.68	1.70	1.14	13.45
Temperature																
Cisco, Utah	(1892-05, 53-67)		1.0	23.30	31.90	39.60	51.20	61.70	71.60	79.60	76.30	66.20	54.10	37.70	26.10	51.60
		1964		24.10	27.50	36.50	50.00	61.60	71.30	81.30	76.00	65.50	55.30	35.30	27.70	51.00
		1965		29.70	32.00	38.00	49.10	59.80	67.80	77.70	75.80	61.10	54.20	43.70	28.90	51.50

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-3. Weighted precipitation and temperature data for irrigated lands within the subbasins of the San Juan Division.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
SAN JUAN RIVER ABOVE ARBOLES, COLORADO																
Precipitation																
Pagosa Springs, Colo.	(1928-32, 34-67)		1.0	2.09	1.46	1.54	1.51	1.15	0.90	1.92	2.29	1.63	2.37	1.21	1.86	19.93
		1964		0.65	0.68	1.08	1.34	0.76	0.06	1.40	2.59	1.91	0.00	2.54	3.85	16.86
		1964		2.46	1.14	1.08	2.17	1.28	0.98	4.13	1.31	3.15	1.74	2.75	4.93	27.09
Temperature																
Pagosa Springs, Colo.	(1928-32, 34-67)		1.0	19.10	24.10	32.10	41.80	49.10	57.40	64.10	62.60	55.70	45.20	32.70	21.70	42.10
		1964		16.90	19.30	26.70	39.00	49.80	56.00	64.80	61.70	55.90	47.00	31.00	20.70	40.70
		1965		22.50	22.20	29.20	41.40	47.40	54.60	64.40	60.60	51.50	46.70	36.20	27.40	42.00
SAN JUAN RIVER ABOVE ARCHLILETA, NEW MEXICO																
Precipitation																
Ignacio, Colo.	(1909-67)		0.70	1.20	1.08	1.22	1.17	0.97	0.75	1.73	1.98	1.44	1.46	0.88	1.22	15.10
Vallecito Dam, Colo.	(1917-18, 42-67)		0.30	2.59	1.69	2.20	2.00	1.51	1.03	2.26	2.98	1.87	2.44	1.71	2.64	24.92
		1964		0.37	0.45	1.64	2.10	0.40	0.17	1.39	4.36	1.92	0.02	1.93	2.86	17.61
		1965		1.85	1.20	1.32	2.33	1.44	1.04	1.57	1.05	2.23	1.08	2.56	4.06	21.73
Temperature																
Ignacio, Colo.	(1909-67)		0.65	22.40	28.50	36.20	44.80	53.10	61.70	68.10	66.20	58.70	48.20	35.30	26.40	45.80
Vallecito Dam, Colo.	(1917-18, 42-67)		0.35	22.00	24.50	30.80	41.60	49.40	57.90	64.80	63.10	57.00	47.50	35.10	26.50	43.30
		1964		21.30	22.10	30.10	40.50	51.80	59.10	68.50	63.50	56.40	49.40	34.10	23.40	43.30
		1965		25.20	25.30	31.50	42.70	49.20	56.50	66.00	63.20	53.70	49.40	39.10	28.80	44.20
ANIMAS RIVER BASIN																
Precipitation																
Durango, Colo.	(1885-67)		0.67	1.62	1.52	1.71	1.34	1.09	0.83	1.96	2.26	1.84	1.88	1.21	1.71	18.97
Aztec Ruins Nat'l Mon., New Mexico	(1910-67)		0.33	0.67	0.66	0.72	0.61	0.57	0.45	1.03	1.22	1.02	1.00	0.60	0.78	9.33
		1962		0.84	1.81	0.60	0.19	0.95	0.37	0.43	0.28	2.08	2.62	1.49	1.27	12.93
		1963		1.77	1.03	0.86	1.03	0.13	0.18	2.24	3.94	0.93	1.52	0.80	0.34	14.77
Temperature																
Durango, Colo.	(1885-67)		0.67	24.90	29.90	36.90	45.10	52.60	60.80	67.10	65.80	59.00	48.40	37.20	27.10	46.20
Aztec Ruins Nat'l Mon., New Mexico	(1910-67)		0.33	28.50	34.40	41.10	50.20	58.80	67.30	74.00	71.90	64.70	53.70	39.40	30.80	51.20
		1962		24.50	34.60	35.20	50.40	54.30	63.40	69.70	68.40	61.90	52.10	41.60	31.80	49.00
		1963		19.20	35.40	38.90	47.00	59.20	62.70	72.20	69.20	64.50	55.40	40.30	29.20	49.40
SAN JUAN RIVER ABOVE FARMINGTON, NEW MEXICO																
Precipitation																
Bloomfield, N. Mex.	(1891-95, 04-67)		1.0	0.48	0.63	0.64	0.61	0.50	0.39	1.03	1.30	0.92	0.86	0.50	0.61	8.47
		1964		0.12	0.18	0.45	0.96	0.14	0.03	1.29	2.28	1.21	0.00	0.62	1.15	8.43
		1965		0.69	0.59	0.37	1.31	0.88	1.03	2.74	1.23	1.20	1.25	1.22	1.51	5.80
Temperature																
Bloomfield, N. Mex.	(1904-67)		1.0	27.80	34.60	41.90	50.60	59.60	69.10	75.20	72.90	65.10	53.00	39.50	29.30	51.50
		1964		28.40	31.20	41.90	49.10	62.60	70.20	78.00	72.50	65.60	57.30	40.00	30.50	52.00
		1965		35.30	34.10	40.30	50.90	58.50	66.80	75.20	73.30	63.00	55.20	46.30	33.60	52.70

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-3. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
LAPLATA RIVER BASIN																
Precipitation																
Fort Lewis, Colo.	(1901-67)		0.58	1.48	1.61	1.50	1.37	1.03	0.81	2.10	2.22	1.75	1.79	1.06	1.65	18.37
Farmington FAA Airport New Mexico	(1942-67)		0.42	0.56	0.47	0.53	0.56	0.47	0.31	0.84	1.19	0.89	1.14	0.48	0.82	8.26
		1961		0.78	0.46	2.25	0.72	0.16	0.08	1.25	2.91	1.63	1.60	0.64	0.94	13.42
		1962		0.52	1.47	0.43	0.41	0.54	0.36	0.42	0.17	1.58	2.88	1.07	0.82	10.67
Temperature																
Fort Lewis, Colo.	(1918-67)		0.58	23.80	26.00	31.80	41.20	49.10	57.90	64.10	62.10	55.00	45.70	33.70	25.50	43.00
Farmington FAA Airport New Mexico	(1942-67)		0.42	28.80	35.10	41.30	51.30	60.70	69.40	75.90	74.60	65.60	54.20	39.90	30.30	52.20
		1961		24.40	31.60	36.70	44.50	55.40	67.30	70.00	68.10	56.00	47.60	34.60	19.60	46.32
		1962		21.10	27.20	27.40	44.80	48.60	58.80	64.00	63.70	57.50	47.90	38.00	29.30	44.03
SAN JUAN RIVER ABOVE SHIPROCK, NEW MEXICO																
Precipitation																
Farmington, N. Mex.	(1942-67)		0.33	0.57	0.50	0.56	0.59	0.46	0.31	0.86	1.13	0.89	1.19	0.49	0.71	8.26
Fruitland, N. Mex.	(1899-24, 38-67)		0.33	0.54	0.54	0.47	0.51	0.40	0.28	0.84	0.86	0.75	0.72	0.43	0.56	6.89
Shiprock, N. Mex. Nato Mount	(1926-42, 44-67)		0.34	0.35	.0.44	0.55	0.52	0.50	0.34	0.70	0.98	0.97	0.68	0.45	0.50	6.98
Chaco Canyon, N. Mex.	(1934-67)			0.39	0.55	0.55	0.42	0.67	0.38	1.11	1.39	1.17	0.91	0.48	0.72	8.74
		1964		0.08	0.08	0.74	1.22	0.19	T	0.74	0.55	2.16	0.00	1.02	1.09	7.87
		1965		0.81	0.48	0.28	1.05	1.03	0.90	1.21	0.55	1.00	1.66	1.09	1.07	11.13
	**	1964		0.10	0.63	0.27	0.48	0.30	0.01	0.97	1.37	1.14	0.00	0.95	0.58	6.80
	**	1965		0.49	0.32	0.26	0.83	0.72	1.19	1.85	1.34	1.47	1.14	0.91	1.18	11.70
Temperature																
Farmington, N. Mex.	(1942-67)		0.33	28.80	35.00	40.90	51.20	60.10	69.80	75.70	73.40	65.50	54.00	39.50	30.60	52.00
Fruitland, N. Mex.	(1899-24, 38-67)		0.33	29.40	34.80	42.50	51.50	60.30	69.60	75.10	73.20	65.30	63.60	39.90	30.50	52.10
Shiprock, N. Mex.	(1926-42, 44-67)		0.34	29.10	35.70	43.40	53.00	61.80	70.80	77.40	74.80	66.80	54.90	40.70	30.60	53.30
		1964		27.90	31.10	37.80	49.80	62.00	80.20	77.20	72.90	65.10	52.90	39.30	30.40	52.20
		1965		33.20	35.10	43.60	51.90	59.10	67.00	76.20	77.30	63.70	55.40	46.20	35.10	52.90
SAN JUAN RIVER ABOVE BLUFF, UTAH																
Precipitation																
Shiprock, N. Mex.	(1926-42, 44-67)		0.06	0.35	0.44	0.55	0.52	0.50	0.34	0.70	0.98	0.97	0.68	0.45	0.50	6.98
Blanding, Utah	(1915-67)		0.04	1.25	1.24	1.06	0.90	0.70	0.47	1.08	1.36	1.25	1.26	1.05	1.47	13.09
Chinle, Arizona	(1908-28, 35-67)		0.19	0.47	0.45	0.80	0.44	0.33	0.23	1.39	1.89	1.20	0.99	0.92	0.90	10.01
Mancos, Colo.	(1898-19, 36-67)		0.18	1.45	1.29	1.70	1.55	1.13	0.73	1.87	2.03	1.36	1.59	1.12	1.31	17.13
Cortez, Colo.	(1929-67)		0.48	1.00	1.05	1.11	1.06	0.85	0.51	1.16	1.54	1.45	1.44	0.83	1.15	13.15
Monticello, Ut.	(1902-67)		0.05	1.14	1.15	1.23	1.04	0.83	0.64	1.70	1.96	1.54	1.91	0.98	1.23	15.35
		1964		0.37	0.16	1.87	1.22	0.44	0.07	1.35	2.08	1.98	0.00	1.80	1.34	12.68
		1965		1.13	0.82	1.44	1.23	2.07	1.20	1.58	1.64	1.68	2.12	1.64	2.10	18.65

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

Table C-3. Continued.

	Years of Record	Model Years	Weight factor[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Annual
Temperature																
Shiprock, N. Mex.	(1926-42, 44-67)		0.10	29.10	35.70	43.40	53.00	61.80	70.80	77.40	74.80	66.80	54.90	40.70	30.60	53.30
Blanding, Utah	(1915-67)		0.08	26.90	32.40	39.10	47.80	56.20	66.20	72.40	70.40	62.70	51.60	38.60	29.40	49.50
Chinle, Arizona	(1908-28, 35-67)		0.23	28.10	36.20	41.20	51.50	61.00	68.90	77.00	74.10	66.10	55.40	43.10	30.70	52.80
Cortez, Colo.	(1929-67)		0.50	27.10	31.80	38.50	47.40	55.90	64.70	71.20	69.60	62.20	51.10	37.30	29.40	48.80
Monticello, Ut.	(1902-04, 24-25, 27-67)		0.09	25.00	28.70	35.20	44.60	52.70	61.90	68.10	66.20	59.50	49.00	36.40	27.80	46.30
		1964		25.90	28.80	35.40	46.10	57.80	65.70	74.80	69.80	62.30	54.20	36.40	29.90	48.90
		1965		30.80	32.10	37.00	47.50	54.20	62.60	71.50	69.50	60.00	52.60	43.80	33.20	49.60
COLORADO RIVER ABOVE LEE'S FERRY, ARIZONA																
Precipitation																
Fruita, Ut.	(1938-67)		0.40	0.33	0.22	0.42	0.56	0.56	0.49	0.87	1.18	0.76	1.01	0.44	0.41	7.25
Emery, Ut.	(1901-67)		0.20	0.48	0.53	0.45	0.42	0.58	0.47	0.75	1.20	0.95	0.75	0.35	0.51	7.44
Hanksville, Ut.	(1910-67)		0.16	0.31	0.27	0.29	0.32	0.35	0.32	0.60	0.83	0.54	0.65	0.31	0.32	5.11
Escalante, Ut.	(1901-67)		0.12	1.02	0.82	0.88	0.64	0.60	0.50	1.42	1.95	1.21	1.04	0.62	0.99	11.69
Boulder, Ut.	(1936-67)		0.12	0.71	0.54	0.52	0.88	0.72	0.57	0.82	1.54	1.10	1.02	0.83	0.78	10.03
		1964		0.11	0.00	0.72	1.30	1.11	0.25	0.86	0.68	0.49	0.00	0.56	0.49	6.75
		1965		0.21	0.37	0.48	2.03	1.35	1.15	1.41	1.39	0.92	0.42	0.73	1.63	12.09
Temperature																
Fruita, Ut.	(1938-67)		0.40	29.80	36.50	44.80	52.20	64.10	71.20	77.10	74.20	67.80	55.40	51.70	32.70	54.00
Emery, Ut.	(1901-67)		0.20	24.10	29.00	36.60	44.90	53.20	61.50	67.50	65.60	58.40	47.90	36.40	26.80	46.00
Hanksville, Ut.	(1911-67)		0.16	24.40	33.40	43.50	53.00	62.20	72.00	78.50	75.30	66.40	53.50	39.00	28.70	52.50
Escalante, Ut.	(1901-13, 16-67)		0.12	26.10	31.10	39.30	47.10	55.20	64.30	70.20	67.80	60.70	49.80	37.60	28.70	48.20
Boulder, Ut.	(1936-67)		0.12	26.70	32.10	35.80	45.80	55.00	63.60	71.50	68.70	60.20	53.30	39.60	30.20	48.50
		1964		25.80	26.70	35.50	47.80	57.60	66.40	77.20	72.40	63.60	56.70	35.10	30.40	49.60
		1965		33.10	33.20	37.90	47.50	55.60	63.90	72.60	71.10	59.30	56.40	43.40	28.80	50.23

---

[a] Portion of irrigated acreage to which a particular precipitation or temperature value is assumed to apply.

APPENDIX D

Listing of Water and Salt Input Stations Computer Correlation Program

BLANK PAGE

Table D-1. Gaging stations used in determining the inflow or discharge to subbasins of the Green Division.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
New Fork River Basin							
	9-1930	New Fork River Below New Fork Lake, Near Cora, Wyo.	1938-present		U.S.G.S.	Correlated	Inflow
	9-1965	Pine Creek above Fremont Lake, Wyo.	1954-present		U.S.G.S.	Correlated	Inflow
	9-1985	Pole Creek below Little Half Moon Lake near Pinedale, Wyo.	1938-present		U.S.G.S.	Correlated	Inflow
	9-1995	Fall Creek near Pinedale, Wyo.	1938-present		U.S.G.S.	Correlated	Inflow
	9-2020	Boulder Creek below Boulder Lake, near Boulder, Wyo.	1938-present		U.S.G.S.	Correlated	Inflow
	9-2030	East Fork near Big Sandy, Wyo.	1938-present	1957-1965	U.S.G.S.	U.S.B.R. & U.S.G.S.	Inflow
	9-2040	Silver Creek near Big Sandy, Wyo.	1938-present		U.S.G.S.	Correlated	Inflow
	9-2050	New Fork River near Big Piney, Wyo.	1954-present	1964-present	U.S.G.S.	U.S.G.S.	Disch.
Green River above LaBarge, Wyoming							
	9-1885	Green River at Warren Bridge, near Daniel, Wyo.	1931-present	1954-1955 & 1962-1964	U.S.G.S.	U.S.G.S.	Inflow
	9-1890	Beaver Creek near Daniel, Wyo.	1941-1954		Correlated	Correlated	Inflow
	9-1895	Horse Creek at Sherman Ranger Station, Wyo.	1954-present		U.S.G.S.	Correlated	Inflow
	9-1915	Cottonwood Creek near Daniel, Wyo.	1940-1954		Correlated	Correlated	Inflow
	9-2050	New Fork River near Big Piney, Wyo.	1954-present	1964-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2055	North Piney Creek near Mason, Wyo.	1931-present		U.S.G.S.	Correlated	Inflow
	9-2060	Middle Piney Creek near Big Piney, Wyo.	1940-1954		Correlated	Correlated	Inflow
	9-2094	Green River near LaBarge, Wyo.	1963-present	1963-present	U.G.S.G.	U.S.G.S.	Disch.
Green River above Fontenelle Reservoir							
	9-2080	LaBarge Creek near LaBarge Meadows Ranger Station, Wyo.	1940-1942 & 1950-present		U.S.G.S.	Correlated	Inflow
	9-2094	Green River near LaBarge, Wyo.	1963-present	1963-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2105	Fontenelle Creek near Herschler Ranch near Fontenelle, Wyo.	1951-present		U.S.G.S.	Correlated	Inflow
	9-2112	Green River below Fontenelle Reservoir, Wyo.	1963-present	1963-1966	U.S.G.S.	U.S.G.S.	Disch.
Big Sandy Creek Basin							
	9-2150	Pacific Creek near Farson, Wyo.	1954-present	1954-1964	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
		Releases from Big Sandy Reservoir		1958-1964	U.S.B.R.	U.S.B.R.	Inflow
		Releases from Eden Reservoir			U.S.B.R.		Inflow
	9-2145	Little Sandy Creek above Eden, Wyo.	1954-present	1954-1964	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2160	Big Sandy Creek below Eden, Wyo.	1954-present	1954-1964	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Green River above Green River, Wyoming							
	9-2112	Green River below Fontenelle Reservoir, Wyo.	1963-present	1963-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-2160	Big Sandy Creek below Eden, Wyo.	1954-present	1954-1964	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2170	Green River near Green River, Wyo.	1951-present	1951-present	U.S.G.S.	U.S.G.S.	Disch.

Preceding page blank

Table D-1. Continued.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
Blacks Fork River Basin							
	9-2185	Blacks Fork near Millburne, Wyo.	1939-present	1939-1966	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2200	East Fork of Smith Fork near Robertson, Wyo.	1952-present	1959-1965	U.S.G.S.	U.S.G.S.	Inflow
	9-2205	West Fork of Smith Fork near Robertson, Wyo.	1939-present	1959-1965	U.S.G.S.	U.S.G.S.	Inflow
	9-2230	Hams Fork near Elk Creek Ranger Station, Wyo.	1952-present		U.S.G.S.	Correlated	Inflow
	9-2247	Blacks Fork near Little America, Wyo.	1962-present	1939-present	U.S.G.S.	U.S.G.S.	Disch.
Green River above Flaming Gorge Dam							
	9-2170	Green River near Green River, Wyo.	1951-present	1951-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2247	Blacks Fork near Little America, Wyo.	1962-present	1939-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2260	Henrys Fork near Lonetree, Wyo.	1942-present		U.S.G.S.	Correlated	Inflow
	9-2265	Middle Fork Beaver Creek near Lonetree, Wyo.	1948-present		U.S.G.S.	Correlated	Inflow
	9-2270	East Fork Beaver Creek near Lonetree, Wyo.	1949-1962		Correlated	Correlated	Inflow
	9-2275	West Fork Beaver Creek near Lonetree. Wyo.	1949-1965		Correlated	Correlated	Inflow
	9-2285	Burnt Fork near Burntfork, Wyo.	1943-present		U.S.G.S.	Correlated	Inflow
	9-2345	Green River near Greendale, Utah	1950-present	1956-present	U.S.G.S.	U.S.G.S.	Disch.
Little Snake River Basin							
	9-2530	Little Snake River near Slater, Colo.	1942-1947 & 1950-present		U.S.G.S.	Correlated	Inflow
	9-2535	Battle Creek near Slater, Colo.	1943-1951		Correlated	Correlated	Inflow
	9-2550	Slater Fork near Slater, Colo.	1931-present	1965-1967	U.S.G.S.	U.S.G.S.	Inflow
	9-2560	Savery Creek near Savery, Colo.	1941-1946 & 1947-present	1965-1967	U.S.G.S.	U.S.G.S.	Inflow
	9-2580	Willow Creek near Dixon, Wyo.	1953-present		U.S.G.S.	Correlated	Inflow
	9-2600	Little Snake River near Lily, Colo.	1921-present	1950-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Yampa River Basin							
	9-2410	Elk River at Clark, Colo.	1930-present		U.S.G.S.	Correlated	Inflow
	9-2441	Fish Creek near Milner, Colo.	1955-present		U.S.G.S.	Correlated	Inflow
	9-2443	Grassy Creek near Mount Harris, Colo.	1958-1966		U.S.G.S.	Correlated	Inflow
	9-2430	Trout Creek near Phippsburg, Colo.	1954-1958		Correlated	Correlated	Inflow
	9-2450	Elkhead Creek near Elkhead, Colo.	1953-present		U.S.G.S.	Correlated	Inflow
	9-2455	North Fork Elkhead Creek near Elkhead, Colo.	1958-present		U.S.G.S.	Correlated	Inflow
	9-2469	Fortification Creek near Craig, Colo.	1956-1960		Correlated	Correlated	Inflow
	9-2500	Milk Creek near Thornburg, Colo.	1952-present	1962-1967	U.S.G.S.	U.S.G.S.	Inflow
	9-2495	Williams Fork at Hamilton, Colo.	1910-1927		Correlated	Correlated	Inflow
	9-2395	Yampa River at Steam Boat Springs, Colo.	1909-present		U.S.G.S.	Correlated	Inflow
	9-2510	Yampa River near Maybell, Colo.	1916-present	1950-present	U.S.G.S.	U.S.G.S.	Disch.
Green River above Jensen, Utah							
	9-2345	Green River near Greendale, Utah	1950-present	1956-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2356	Pot Creek above Diversions near Vernal, Utah	1957-present		U.S.G.S.	Correlated	Inflow
	9-2510	Yampa River near Maybell, Colo.	1916-present	1950-present	U.S.G.S.	U.S.G.S.	Inflow
	9-2600	Little Snake River near Lily, Colo.	1921-present	1950-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2610	Green River near Jensen, Utah	1946-present	1962-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.

Table D-1. Continued.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
Ashley Creek Basin							
	9-2665	Ashley Creek near Vernal, Utah	1913-present		U.S.G.S.	Correlated	Inflow
	9-2705	Dry Fork at mouth, near Dry Fork, Utah	1954-present		U.S.G.S.	Correlated	Inflow
		Releases from Steinaker Reservoir			U.S.B.R.		Inflow
	9-2715	Ashley Creek near Jensen, Utah	1946-present	1947-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Duchesne River above Duchesne, Utah							
	9-2770	Duchesne River at Hanna, Utah	1953-1960	1956-1964	Correlated	U.S.G.S. & U.S.B.R.	Inflow
	9-2790	Rock Creek near Mountain Home, Utah	1937-present		U.S.G.S.	Correlated	Inflow
	9-2850	Strawberry River near Soldier Springs, Utah	1942-1956 & 1963-present	1951-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2865	Red Creek near Fruitland, Utah	1955-1961	1941-1958	Correlated	U.S.G.S.	Inflow
	9-2880	Currant Creek near Fruitland, Utah	1934-present	1947-1962	U.S.G.S.		Inflow
	9-2885	Strawberry River at Duchesne, Utah	1914-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
	9-2795	Duchesne River at Duchesne, Utah	1917-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Duchesne River above Randlett, Utah							
	9-2675	Mosby Canal near Lapoint, Utah	1954-present		U.S.G.S.	Correlated	Inflow
	9-2795	Duchesne River at Duchesne, Utah	1917-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2885	Strawberry River at Duchesne, Utah	1914-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2889	Sowers Creek near Duchesne, Utah	1964-present		U.S.G.S.	Correlated	Inflow
	9-2910	Lake Fork River below Moon Lake near Mountain Home, Utah	1942-present	1958-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-2925	Yellowstone River near Altonah, Utah	1944-present	1962-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-2970	Uinta River near Neola, Utah	1929-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2980	Farm Creek near Whiterocks, Utah	1949-present		U.S.G.S.	Correlated	Inflow
	9-2995	Whiterocks River near Whiterocks, Utah	1913-present	1941-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3020	Duchesne River near Randlett, Utah	1942-present	1950-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
White River Basin							
	9-3028	White River near Buford, Colo.	1956-present		U.S.G.S.	Correlated	Inflow
	9-3040	South Fork White River at Buford, Colo.	1951-present	1957-1965	U.S.G.S.	U.S.G.S.	Inflow
	9-3041	Big Beaver Creek near Buford, Colo.	1958-1964		Correlated	Correlated	Inflow
	9-3043	Coal Creek near Meeker, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-3065	White River near Watson, Utah	1923-present	1947-present	U.S.G.S.	U.S.G.S.	Disch.

Table D-1. Continued.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
Green River above Ouray, Utah	9-2610	Green River near Jensen, Utah	1946-present	1962-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2620	Big Brush Creek near Vernal, Utah	1939-present	1947-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-2630	Little Brush Creek near Vernal, Utah	1946-1952		Correlated	Correlated	Inflow
	9-2715	Ashley Creek near Jensen, Utah	1946-present	1947-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3020	Duchesne River near Randlett, Utah	1942-present	1950-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3065	White River near Watson, Utah	1923-present	1947-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3070	Green River near Ouray, Utah	1947-1955 & 1956-1966	1948-1965	U.S.G.S.	U.S.G.S.	Disch.
Price River Basin	9-3128	Willow Creek near Castle Gate, Utah	1962-present		U.S.G.S.	Correlated	Inflow
	9-3130	Price River near Heiner, Utah	1934-present	1948-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3145	Price River at Woodside, Utah	1945-present	1946-1949 1951-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Green River above Green River, Utah	9-3070	Green River near Ouray, Utah	1947-1955 & 1956-1966	1948-1965	U.S.G.S.	U.S.G.S.	Inflow
	9-3075	Willow Creek above diversions near Ouray, Ut.	1950-1955 & 1957-present		U.S.G.S.	Correlated	Inflow
	9-3085	Minnie Maud Creek near Myton, Utah	1950-1955 & 1957-present		U.S.G.S.	Correlated	Inflow
	9-3145	Price River at Woodside, Utah	1945-present	1946-1949 1951-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3150	Green River at Green River, Utah	1904-present	1928-present	U.S.G.S.	U.S.G.S.	Disch.
San Rafael River Basin	9-3180	Huntington Creek near Huntington, Utah	1930-present	1933-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3245	Cottonwood Creek near Orangeville, Utah	1932-present	1956-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3265	Ferron Creek (upper station) near Ferron, Ut.	1947-present	1949-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3285	San Rafael River near Green River, Utah	1945-present	1946-present	U.S.G.S.	U.S.G.S.	Disch.

Table D-2. Gaging stations used in determining the inflow or discharge to subbasins of the Grand Division.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
Colorado River above Hot Sulphur Springs, Colo.							
	9-190	Colorado River below Lake Granby, Colo.	1950-present		U.S.G.S.	Correlated	Inflow
	9-210	Willow Creek below Willow Creek Reservoir, Colo.	1953-present		U.S.G.S.	Correlated	Inflow
	9-240	Fraser River near Winter Park, Colo.	1910-present		U.S.G.S.	Correlated	Inflow
	9-250	Vasquez Creek near Winter Park, Colo.	1933-present		U.S.G.S.	Correlated	Inflow
	9-265	St. Louis Creek near Fraser, Colo.	1933-present		U.S.G.S.	Correlated	Inflow
	9-320	Ranch Creek near Fraser, Colo.	1934-present		U.S.G.S.	Correlated	Inflow
	9-330	Meadow Creek near Tabernash, Colo.	1940-1956		Correlated	Correlated	Inflow
	9-345	Colorado River at Hot Sulphur Springs, Colo.	1904-present	1948-present	U.S.G.S.	U.S.G.S.	Disch.
Eagle River Basin							
	9-630	Eagle River at Red Cliff, Colo.	1944-present		U.S.G.S.	Correlated	Inflow
	9-634	Turkey Creek near Red Cliff, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-645	Homestake Creek near Red Cliff, Colo.	1944-present		U.S.G.S.	Correlated	Inflow
	9-651	Cross Creek near Minturn, Colo.	1957-1963		Correlated	Correlated	Inflow
	9-661	Bighorn Creek near Minturn, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-662	Booth Creek near Minturn, Colo.	1964-present		U.S.G.S.	Correlated	Inflow
	9-663	Middle Creek near Minturn, Colo.	1964-present		U.S.G.S.	Correlated	Inflow
	9-664	Red Sandstone Creek near Minturn, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-665	Gore Creek near Minturn, Colo.	1948-1956		Correlated	Correlated	Inflow
	9-680	Brush Creek near Eagle, Colo.	1950-present		U.S.G.S.	Correlated	Inflow
	9-695	Gypsum Creek near Gypsum, Colo.	1950-present		U.S.G.S.	Correlated	Inflow
	9-700[a]	Eagle River below Gypsum, Colo.	1946-present	1947-present	U.S.G.S.	U.S.G.S.	Disch.
Colorado River above Glenwood Springs, Colo.							
	9-345	Colorado River at Hot Sulphur Springs, Colo.	1904-present	1948-present	U.S.G.S.	U.S.G.S.	Inflow
	9-360	Williams Fork near Leal, Colo.	1933-present		U.S.G.S.	Correlated	Inflow
	9-365	Keyser Creek near Leal, Colo.	1943-1952		Correlated	Correlated	Inflow
	9-390	Troublesome Creek near Pearmont, Colo.	1953-present		U.S.G.S.	Correlated	Inflow
	9-400	East Fork Troublesome Creek near Troublesome, Colo.	1953-1967		U.S.G.S.	Correlated	Inflow
	9-410	Muddy Creek near Kremmling, Colo.	1955-present		U.S.G.S.	Correlated	Inflow
	9-411	Antelope Creek near Kremmling, Colo.	1955-present		U.S.G.S.	Correlated	Inflow
	9-412	Red Dirt Creek near Kremmling, Colo.	1955-present		U.S.G.S.	Correlated	Inflow
	9-413	Pass Creek near Kremmling, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-575	Blue River below Green Mountain Reservoir, Colo.	1937-present	1947-1958	U.S.G.S.	U.S.G.S.	Inflow
	9-595	Piney River near State Bridge, Colo.	1944-present		U.S.G.S.	Correlated	Inflow
	9-605	Rock Creek near Toponas, Colo.	1952-present		U.S.G.S.	Correlated	Inflow
	9-700[a]	Eagle River below Gypsum, Colo.	1946-present	1947-present	U.S.G.S.	U.S.G.S.	Inflow
	9-725[b]	Colorado River at Glenwood Springs, Colo.	1899-present	1942-present	U.S.G.S.	U.S.G.S.	Disch.

[a] Salinity records for Station 9-700 were taken at Station 690.

[b] Salinity records for Station 9-725 were taken at Station 9-711.

Table D-2. Continued.

Subbasins	Station Number	Station Name	Records available Hydrologic	Records available Salinity	Source of records Hydrologic	Source of records Salinity	Inflow or Discharge Station
Roaring Fork River Basin							
	9-735	Roaring Fork at Aspen, Colo.	1931-1964	1955-1957	Correlated	U.S.G.S.	Inflow
	9-740	Hunters Run Creek near Aspen, Colo.	1951-1956		Correlated	Correlated	Inflow
	9-780	Fryingpan River at Norrie, Colo.	1947-present	1952-1961	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-785	North Fork Fryingpan River near Norrie, Colo.	1947-present	1955-1960	U.G.S.G.	U.S.G.S. & U.S.B.R.	Inflow
	9-795	Lime Creek near Thomasville, Colo.	1951-1956	1953-1956	Correlated	U.S.G.S. & U.S.B.R.	Inflow
	9-808	West Sopris Creek near Basalt, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-820	Avalanche Creek near Redstone, Colo.	1955-1957		Correlated	Correlated	Inflow
	9-830	Thompson Creek near Carbondale, Colo.	1950-1960 & 1964-present	1957-1963	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-837	Prince Creek near Carbondale, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-840	Cattle Creek near Carbondale, Colo.	1950-1955 & 1962-present		U.S.G.S.	Correlated	Inflow
	9-846	Fourmile Creek near Glenwood Springs, Colo.	1957-1965		U.S.G.S.	Correlated	Inflow
	9-850	Roaring Fork River at Glenwood Springs, Colo.	1910-present	1947-1967	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Colorado River above Plateau Creek							
	9-725b	Colorado River at Glenwood Springs, Colo.	1899-present	1942-present	U.S.G.S.	U.S.G.S.	Inflow
	9-850	Roaring Fork River at Glenwood Springs, Colo.	1910-present	1947-1967	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-855	Canyon Creek near New Castle, Colo.	1954-1960		U.S.G.S.	Correlated	Inflow
	9-875	Elk Creek at New Castle, Colo.	1954-1960	1948-1958	U.S.G.S.	U.S.G.S.	Inflow
	9-880	Baldy Creek near New Castle, Colo.	1955-1961		U.S.G.S.	Correlated	Inflow
	9-895	West Divide Creek near Raven, Colo.	1955-present	1957-1961	U.S.G.S.	U.S.G.S.	Inflow
	9-920	Rifle Creek near Rifle, Colo.	1939-1946 1952-1964	1940-1959	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-925	Beaver Creek near Rifle, Colo.	1952-present	1957-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-926	Battlement Creek near Grand Valley, Colo.	1956-1965	1958-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-930	Parachute Creek near Grand Valley, Colo.	1948-1954 & 1964-present		Correlated	Correlated	Inflow
	9-942	Roan Creek above Clear Creek near De Beque, Colo.	1963-present		Correlated		Inflow
	9-955	Colorado River near Cameo, Colo.	1933-present	1933-present	U.S.G.S.	U.S.G.S.	Disch.
Plateau Creek Basin							
		Releases from Vega Reservoir			Colo. St. Engineers		Inflow
	9-968	Buzzard Creek below Owens Creek near Heiberger, Colo.	1955-present	1963-1967	U.S.G.S.	U.S.G.S.	Inflow
	9-976	Brush Creek near Colbran, Colo.	1955-1967	1963-1967	U.S.G.S.	U.S.G.S.	Inflow

[b] Salinity records for Station 9-725 were taken at Station 9-711.

Table D-2. Continued.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
	9-995	Big Creek at Upper Station, Colo.	1946-1956		Correlated	Correlated	Inflow
	9-1005	Cottonwood Creek at Upper Station, Colo.	1946-1957		Correlated	Correlated	Inflow
	9-1015	Bull Creek at Upper Station near Molina, Colo.	1946-1953		Correlated	Correlated	Inflow
	9-1045	Mesa Creek near Mesa, Colo.	1951-1960		Correlated	Correlated	Inflow
	9-1050	Plateau Creek near Cameo, Colo.	1935-present	1947-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Gunnison River above Gunnison, Colorado							
	9-1100	Taylor River at Almont, Colo.	1910-present		U.S.G.S.	Correlated	inflow
	9-1122	East River below Cement Creek near Crested Butte, Colo.	1963-present		U.S.G.S.	Correlated	Inflow
	9-1133	Ohio Creek at Baldwin, Colo.	1958-present		U.S.G.S.	Correlated	Inflow
	9-1155	Tomichi Creek at Sargents, Colo.	1937-present	1957-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1180	Quartz Creek near Ohio, Colo.	1937-1950 & 1959-present		U.S.G.S.	Correlated	Inflow
	9-1145	Gunnison River near Gunnison, Colo.	1944-present	1945-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
	9-1190	Tomichi Creek at Gunnison, Colo.	1937-present	1954-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
Gunnison River above North Fork Gunnison River							
	9-1145	Gunnison River near Gunnison, Colo.	1944-present	1945-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1190	Tomichi Creek at Gunnison, Colo.	1937-present	1954-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1220	Cebolla Creek at Powderhorn, Colo.	1937-1955		Correlated	Correlated	Inflow
	9-1225	Soap Creek near Sapinero, Colo.	1955-1966	1956-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-1245	Lake Fork at Gateview, Colo.	1937-present		U.S.G.S.	Correlated	Inflow
	9-1250	Curecanti Creek near Sapinero, Colo.	1945-present	1956-1958	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1260	Cimarron River near Cimarron, Colo.	1954-present	1956-1958	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1275	Crystal Creek near Maher, Colo.	1945-1954 & 1960-present	1957-1958	U.S.G.S.	U.S.G.S.	Inflow
	9-1285	Smith Fork near Crawford, Colo.	1935-present	1958-1959	U.S.G.S.	U.S.G.S.	Inflow
		Diversions through Gunnison Tunnel			U.S.B.R.		Export
		Diversions from Cimarron River			U.S.B.R.		Export
		Releases from Fruitland Reservoir	1957-present		Colo. St. Engineers		Inflow
	9-1297[c]	Gunnison River above North Fork Gunnison River near Lazear, Colo.	1903-present	1944-1959	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.

---

[c] Data for Station 9-1297 was obtained by using Station 9-1280 plus estimated outflow from Smith Fork.

Table D-2. Continued.

Subbasins	Station Number	Station Name	Records available		Source of record		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
Uncompahgre River Basin							
	9-1462	Uncompahgre River near Ridgway, Colo.	1958-present	1959-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-1464	West Fork Dallas Creek near Ridgway, Colo.	1955-present	1959-1961	U.S.G.S.	U.S.G.S.	Inflow
	9-1465	East Fork Dallas Creek near Ridgway, Colo.	1947-1953 & 1960-present	1958-1961	U.S.G.S.	U.S.G.S.	Inflow
	9-1465.5	Beaver Creek near Ridgway, Colo.	1960-present		U.S.G.S.	Correlated	Inflow
	9-1466	Pleasant Valley Creek near Noel, Colo.	1955-1967		U.S.G.S.	Correlated	Inflow
	9-1471	Cow Creek near Ridgway, Colo.	1955-present	1957-1961	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1495	Uncompahgre River at Delta, Colo.	1938-present	1957-1965	U.S.G.S.	U.S.G.S. &	Disch.
Gunnison River above Grand Junction, Colorado							
	9-1297[c]	Gunnison River above North Fork Gunnison River near Lazear, Colo.	1903-present	1944-1959	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1325	North Fork Gunnison River near Somerset, Colo.	1933-present	1956-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1327	Main Hubbard Creek near Paonia, Colo.	1960-present		U.S.G.S.	Correlated	Inflow
	9-1328	Middle Hubbard Creek near Paonia, Colo.	1960-present		U.S.G.S.	Correlated	Inflow
	9-1329	West Hubbard Creek near Paonia, Colo.	1960-present		U.S.G.S.	Correlated	Inflow
	9-1345	Leroux Creek near Cedaredge, Colo.	1936-1956 & 1960-present	1956-1958	U.S.G.S.	U.S.B.R.	Inflow
	9-1347	Cow Creek near Cedaredge, Colo.	1960-present		U.S.G.S.	Correlated	Inflow
	9-1378	Dirty George Creek near Grand Mesa, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-1392	Ward Creek near Grand Mesa, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-1402	Kiser Creek near Grand Mesa, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-1407	Cottonwood Creek near Grand Mesa, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-1412	Youngs Creek near Grand Mesa, Colo.	1957-present		U.S.G.S.	Correlated	Inflow
	9-1430	Surface Creek near Cedaredge, Colo.	1939-present	1957-1958	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1495	Uncompahgre River at Delta, Colo.	1938-present	1957-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1520	Kannah Creek near Whitewater, Colo.	1922-present		U.S.G.S.	Correlated	Inflow
	9-1525	Gunnison River near Grand Junction, Colo.	1916-present	1931-present	U.S.G.S.	U.S.G.S.	Disch.
Colorado River above Colorado-Utah State Line							
	9-955	Colorado River near Cameo, Colo.	1933-present	1933-present	U.S.G.S.	U.S.G.S.	Inflow
	9-1050	Plateau Creek near Cameo, Colo.	1935-present	1947-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1525	Gunnison River near Grand Junction, Colo.	1916-present	1931-present	U.S.G.S.	U.S.G.S.	Inflow
	9-1635	Colorado River near Colorado-Utah State Line	1951-present	1957-present	U.S.G.S.	U.S.G.S. & P.H.S.	Disch.

[c] Data for Station 9-1297 was obtained by using Station 9-1280 plus estimated outflow from Smith Fork.

Table D-2. Continued.

Subbasins	Station Number	Station Name	Records available Hydrologic	Records available Salinity	Source of record Hydrologic	Source of record Salinity	Inflow or Discharge Station
San Miguel River Basin							
	9-1725	San Miguel River near Placerville, Colo.	1942-present	1957-1966	U.S.G.S.	U.S.G.S. &	Inflow
	9-1730	Beaver Creek near Norwood, Colo.	1941-1961 & 1962-1967		U.S.G.S.	Correlated	Inflow
	9-1735	Horsefly Creek near Sams, Colo.	1942-1951		Correlated	Correlated	Inflow
	9-1745	Cottonwood Creek near Nucla, Colo.	1942-1951		Correlated	Correlated	Inflow
	9-1765	Tabeguache Creek near Nucla, Colo.	1946-1953		Correlated	Correlated	Inflow
		Discharges from Gurley Reservoir			Colo. State Engineers		Inflow
	9-1770	San Miguel River at Uravan, Colo.	1954-1962	1947-1963	Correlated	U.S.G.S. & U.S.B.R.	Disch.
Dolores River Basin							
	9-1665	Dolores River at Dolores, Colo.	1921-present	1953-1960	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-1681	Disappointment Creek near Dove Creek, Colo.	1957-present	1958-1960	U.S.G.S.	U.S.B.R.	Inflow
	9-1770	San Miguel River at Uravan, Colo.	1954-1962	1961-1965	Correlated	U.S.G.S.	Inflow
	9-1775	Taylor Creek near Gateway, Colo.	1944-1967		U.S.G.S.	Correlated	Inflow
		Exports to San Juan River above Bluff, Utah			U.S.B.R.		
	9-1800	Dolores River near Cisco, Utah	1950-present	1931-present	U.S.G.S.	U.S.G.S.	Disch.
Colorado River above Cisco, Utah							
	9-1635	Colorado River near Colorado-Utah State Line	1951-present	1957-present	U.S.G.S.	U.S.G.S. & P. H. S.	Inflow
	9-1800	Dolores River near Cisco, Utah	1950-present	1931-present	U.S.G.S.	U.S.G.S.	Inflow
	9-1805	Colorado River near Cisco, Utah	1895-present	1928-present	U.S.G.S.	U.S.G.S.	Disch.

Table D-3. Gaging stations used in determining the inflow or discharge to subbasins of the San Juan Division.

Subbasins	Station Number	Station Name	Records available		Source of records		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
San Juan River above Arboles, Colorado							
	9-3400	East Fork San Juan River near Pagosa Springs, Colo.	1935-present	1957-1959	U.S.G.S.	U.S.G.S.	Inflow
	9-3415	West Fork San Juan River near Pagosa Springs, Colo.	1935-1960	1948-1959	Correlated	U.S.G.S.	Inflow
	9-3430	Rio Blanco near Pagosa Springs, Colo.	1935-present	1961-1965	U.S.G.S.	U.S.G.S.	Inflow
	9-3435	Rito Blanco near Pagosa Springs, Colo.	1935-1952		Correlated	Correlated	Inflow
	9-3460	Navajo River at Edith, Colo.	1912-present		U.S.G.S.	Correlated	Inflow
	9-3464	San Juan River near Carracas, Colo.	1961-present	1964-1966	U.S.G.S.	U.S.G.S.	Disch.
San Juan River above Archuleta, New Mexico							
	9-3464	San Juan River near Carracas, Colo.	1961-present	1964-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-3498	Piedra River near Arboles, Colo.	1962-present	1965-1966	U.S.G.S.	U.S.G.S.	Inflow
	9-3535	Los Pinos River near Bayfield, Colo.	1927-present	1948-1958	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3550	Spring Creek at La Boca, Colo.	1950-present	1955-1958	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3555	San Juan River near Archuleta, New Mexico	1954-present	1954-present	U.S.G.S.	U.S.G.S.	Disch.
Animas River Basin							
	9-3615	Animas River at Durango, Colo.	1912-present	1948-1959	U.S.G.S.	U.S.G.S.	Inflow
	9-3629	Florida River near Hermosa, Colo.	1955-1963		U.S.G.S.	Correlated	Inflow
	9-3631	Salt Creek near Oxford, Colo.	1956-1963	1959-1960	U.S.G.S.	U.S.B.R.	Inflow
	9-3645	Animas River at Farmington, N.M.	1912-present	1940-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
San Juan River above Farmington, New Mexico							
	9-3645	Animas River at Farmington, N.M.	1912-present	1940-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3555	San Juan River near Archuleta, N.M.	1954-present	1954-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3650	San Juan River at Farmington, N.M.	1912-present	1959-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
LaPlata River Basin							
	9-3655	LaPlata River at Hesperus, Colo.	1917-present	1948-1963	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3675	LaPlata River near Farmington, N.M.	1938-present	1957-1965	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.
San Juan River above Shiprock, New Mexico							
	9-3650	San Juan River at Farmington, N.M.	1912-present	1959-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3675	LaPlata River near Farmington, N.M.	1938-present	1957-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3680	San Juan River at Shiprock, N.M.	1927-present	1941-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Disch.

Table D-3. Continued.

Subbasins	Station Number	Station Name	Records available		Source of record		Inflow or Discharge Station
			Hydrologic	Salinity	Hydrologic	Salinity	
San Juan River above Bluff, Utah							
	9-3680	San Juan River at Shiprock, N.M.	1927-present	1941-present	U.S.G.S.	U.S.G.S. & U.S.B.R.	Inflow
	9-3685	West Mancos River near Mancos, Colo.	1938-1953		Correlated	Correlated	Inflow
	9-3690	East Mancos River near Mancos, Colo.	1937-1951		Correlated	Correlated	Inflow
	9-3695	Middle Mancos River near Mancos, Colo.	1937-1951		Correlated	Correlated	Inflow
	9-3790	Comb Wash near Bluff, Utah	1959-present		U.S.G.S.	Correlated	Inflow
		Imports from Dolores River Basin			U.S.B.R.		Inflow
	9-3795	San Juan River near Bluff, Utah	1914-present	1927-present	U.S.G.S.	U.S.G.S.	Disch.
Colorado River above Lee's Ferry, Arizona							
	9-1805	Colorado River near Cisco, Utah	1895-present	1928-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3150	Green River at Green River, Utah	1904-present	1928-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3160	Browns Wash near Green River, Utah	1949-present		U.S.G.S.	Correlated	Inflow
	9-3155	Saleratus Wash at Green River, Utah	1949-present		U.S.G.S.	Correlated	Inflow
	9-3285	San Rafael River near Green River, Utah	1945-present	1946-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3295	Fremont River near Fremont, Utah	1949-1958		U.S.G.S.	Correlated	Inflow
	9-3305	Muddy Creek near Emery, Utah	1949-1966		U.S.G.S.	Correlated	Inflow
	9-3315	Ivie Creek above Diversions near Emery, Utah	1950-1961		Correlated	Correlated	Inflow
	9-3340	North Wash near Hite, Utah	1950-present		U.S.G.S.	Correlated	Inflow
	9-3345	White Canyon near Hite, Utah	1950-1966		U.S.G.S.	Correlated	Inflow
	9-3355	North Creek near Escalante, Utah	1950-1955		U.S.G.S.	Correlated	Inflow
	9-3365	Birch Creek at mouth near Escalante, Utah	1951-1955		U.S.G.S.	Correlated	Inflow
	9-3370	Pine Creek near Escalante, Utah	1950-1955 & 1957-present		U.S.G.S.	Correlated	Inflow
	9-3380	East Fork Boulder Creek near Boulder, Utah	1950-1955 & 1957-present		U.S.G.S.	Correlated	Inflow
	9-3385	East Fork Deer Creek near Boulder, Utah	1950-1955		U.S.G.S.	Correlated	Inflow
	9-3795	San Juan River near Bluff, Utah	1914-present	1927-present	U.S.G.S.	U.S.G.S.	Inflow
	9-3800	Colorado River at Lee's Ferry, Arizona	1895-present	1928-present	U.S.G.S.	U.S.G.S.	Disch.

Stream Flow Correlation Program

```
@H FOR SFCP
   95 CONTINUE
      WRITE(7,100)
  100 FORMAT('SEND TO  LEON HYATT  UWRL, USU, LOGAN UTAH 84321')
      DIMENSION Y(70,13),SUMYC(13),AVEYC(13)
      DIMENSION R(13),A(13),B(13),C(70,1)
      REAL NAME2(13)
      INTEGER LL(70)
   10 FORMAT(13A6)
      READ(5,10) NAME2
   12 FORMAT(9I5)
C     MY------MUST BE EQ OR LT FIRST YEAR OF ANY TIME BASE USED
C     NY------MUST BE EQ OR GT LAST YEAR OF ANY TIME BASE USED
C     NYYR----EQ TO LAST YEAR OF CORRELATED STATION RECORD
C     LY------CORRELATED STATION DATA IN AC-FT--0--1000AC-FT--1--
C     NSC-----CORRELATE DATA--0--SKIP CORRELATION--1--
C     NP------PUNCH DATA CARDS--1--DO NOT PUNCH--0--
C     LO------LOG-LOG REG--0--LINEAR REG--1--
C     NRD-----12F6.0 FORMAT--0--12F5.0 FORMAT--1--Y(I,J) ARRAY
C     NNRD----12F6.0 FORMAT--0--12F5.0 FORMAT--1--X(I,J) ARRAY
      READ(5,12)MY,NY,NYYR,LY,NSC,NP,LO,NRD,NNRD
      DO 14 I=MY,NY
      DO 14 J=1,13
   14 Y(I,J)=0.0
      K=0
   16 I=MY
C     Y(I,J)--ARRAY IDENTIFING CORRELATED STATION
   18 CONTINUE
      IF(I.GT.NYYR) GO TO 22
      IF(NRD.EQ.1) GO TU 180
      READ(5,20)II,(Y(I,J),J=1,12)
      GO TO 181
  180 READ(5,56) II, (Y(I,J),J=1,12)
   20 FORMAT(6X,I2,12F6.0)
  181 CONTINUE
      IF(I.EQ.II) GO TO 28
      II=I
   22 CONTINUE
      K=K+1
      LL(K)=I
      IF(I.EQ.(II-1)) GO TO 24
      IF(I.EQ.NY) GO TO 11
      I=I+1
      GO TO 22
   24 I=II
      DO 26 J=1,12
   26 Y(I,J)=Y(II,J)
      DO 25 J=1,12
   25 Y(II,J)=0.0
   28 I=I+1
      IF(I.LE.NY) GO TO 18
   11 CONTINUE
      N=1
      Y(I,13)=0.0
      DO 40 I=MY,NY
      IF(K.EQ.0) GO TO 34
      IF(LL(N).NE.I) GO TO 34
      N=N+1
      GO TO 40
   34 DO 36 J=1,12
   36 Y(I,13)=Y(I,13)+Y(I,J)
      C(I,1)=Y(I,13)
      IF(LY.EQ.0) GO TO 40
      DO 38 J=1,13
   38 Y(I,J)=1000.0*Y(I,J)
   40 CONTINUE
      T=NY-MY+1-K
   44 DO 46 J=1,13
   46 SUMYC(J)=0.0
      DO 48 J=1,13
      DO 50 I=MY,NY
      SUMYC(J)=SUMYC(J)+Y(I,J)
   50 CONTINUE
      AVEYC(J)=SUMYC(J)/T
   48 CONTINUE
      WRITE(6,33)NAME2
   33 FORMAT(1H1,36X,13A6)
      WRITE(6,47)
   47 FORMAT(1H0,6H WATER)
      WRITE(6,49)
   49 FORMAT(2X,4HYEAR,4X,3HOCT5X,3HNOV,5X,3HDEC,5X,3HJAN,5X,3HFEB,5X,3H
     1MAR,5X3HAPR,5X,3HMAY,5X,3HJUN,5X,3HJUL,5X,3HAUG,5X,3HSEP,4X,6HANNU
     2AL)
      N=1
      DO 54 I=MY,NY
      IF(K.EQ.0) GO TO 52
      IF(LL(N).NE.I) GO TO 52
      N=N+1
      GO TO 54
   52 WRITE(6,53) I,(Y(I,J),J=1,13)
   53 FORMAT(2X,2H19,I2,12F8.0,F10.0)
   54 CONTINUE
      WRITE(6,55)(AVEYC(J),J=1,13)
   55 FORMAT(/6H  AVE.,12F8.0,F10.0)
      WRITE(6,21) T
   21 FORMAT(/18H  NUMBER OF YEARS ,F4.0)
      IF(NSC.NE.0) GO TO 98
      DIMENSION X(70,13),SUMXC(13),AVEXC(13)
      REAL NAME4(13)
      READ(5,63)NAME4
   63 FORMAT(13A6)
C     MX------FIRST YEAR OF BASE STATION RECORD EQ OR LT MY
C     NX------LAST YEAR OF BASE STATION RECORD EQ OR GT NY
C     LX------BASE STATION DATA IN AC-FT--0--1000AC-FT--1--
      READ(5,61)MX,NX,LX
   61 FORMAT(3I5)
      WRITE(6,67)NAME4
   67 FORMAT(1H1,36X,13A6)
      WRITE(6,47)
      WRITE(6,49)
C     X(I,J)--ARRAY IDENTIFING BASE STATION
      DO 64 I=MX,NX
      IF(NNRD.EQ.1) GO TO 182
      READ(5,20)I2,(X(I,J),J=1,12)
      GO TO 183
  182 READ(5,56) I2, (X(I,J),J=1,12)
   56 FORMAT(12X,I2,12F5.0)
  183 CONTINUE
   64 CONTINUE
      X(I,13)=0.0
      DO 74 I=MX,NX
      DO 68 J=1,12
   68 X(I,13)=X(I,13)+X(I,J)
      IF(LX.EQ.0) GO TO 74
      DO 72 J=1,13
   72 X(I,J)=1000.0*X(I,J)
   74 WRITE(6,53)I,(X(I,J),J=1,13)
      DO 76 J=1,13
   76 SUMXC(J)=0.0
      DO 80 J=1,13
      N=1
      DO 78 I=MY,NY
      IF(K.EQ.0) GO TO 77
      IF(LL(N).NE.I) GO TO 77
      N=N+1
      GO TO 78
   77 SUMXC(J)=SUMXC(J)+X(I,J)
   78 CONTINUE
      AVEXC(J)=SUMXC(J)/T
   80 CONTINUE
      WRITE(6,51)(AVEXC(J),J=1,13)
   51 FORMAT(/6H +AVE.,12F8.0,F10.0)
      WRITE(6,79)
   79 FORMAT(//68H +   AVE. GIVEN FOR YEARS OF CONCURRENT DATA WITH CORR
     1ELATED STATION)
      DO 86 J=1,13
      N=1
      SX2=0.0
      SY2=0.0
      SXY=0.0
      IF(LO.NE.0) GO TO 120
      AVEY=ALOG(AVEYC(J))
      AVEX=ALOG(AVEXC(J))
      GO TO 122
  120 AVEY=AVEYC(J)
      AVEX=AVEXC(J)
  122 DO 84 I=MY,NY
      IF(K.EQ.0) GO TO 82
      IF(LL(N).NE.I) GO TO 82
      N=N+1
      GO TO 84
   82 IF(LO.NE.0) GO TO 124
      SUMX=ALOG(X(I,J))
      SUMY=ALOG(Y(I,J))
      GO TO 126
  124 SUMX=X(I,J)
      SUMY=Y(I,J)
  126 DX=SUMX-AVEX
      DY=SUMY-AVEY
      SX2=SX2+DX*DX
      SY2=SY2+DY*DY
      SXY=SXY+DX*DY
   81 FORMAT(10X,9F10.5)
   84 CONTINUE
      CX=SQRT(SY2/SX2)
      SX2=SX2*CX*CX
      SXY=SXY*CX
      BB=(SX2-SY2)/SXY
      IF(SXY.LT.0.) GO TO 87
      B(J)=0.5*(-BB+SQRT(BB*BB+4.0))
      GO TO 65
   87 B(J)=0.5*(-BB-SQRT(BB*BB+4.))
   65 CONTINUE
      B1=B(J)
      R2=1.0-(SY2-B1*(2.0*SXY-B1*SX2))/((1.0+B1*B1)*SQRT(SX2*SY2))
      R(J)=SQRT(R2)
      B(J)=B(J)*CX
      IF(LO.NE.0) GO TO 128
      A(J)=EXP(AVEY-B(J)*AVEX)
      GO TO 86
  128 A(J)=AVEY-B(J)*AVEX
   86 CONTINUE
   98 CONTINUE
C     M1------FIRST YEAR OF NORMAL TIME BASE EQ OR GT MY
C     N1------LAST YEAR OF NORMAL TIME BASE EQ OR LT NY
C     M2------FIRST YEAR OF ANY TIME BASE EQ OR GT MY
C     N2------LAST YEAR OF ANY TIME BASE EQ OR LT NY
C     NSP-----COMPUTE 2ND TIME BASE--0--SKIP 2ND TIME BASE--1--
      READ(5,85)M1,N1,M2,N2,NSP
   85 FORMAT(5I5)
      WRITE(6,33)NAME2
   13 FORMAT(/6H  R   ,12F8.3)
   15 FORMAT(1X,5H A   ,12F8.3)
   17 FORMAT(1X,5H B   ,12F8.3)
   58 FORMAT(/6H  R   ,12F8.3,10X,F10.3)
   59 FORMAT(1X,5H A   ,12F8.3,10X,F10.3)
   60 FORMAT(1X,5H B   ,12F8.3,10X,F10.3)
   57 FORMAT(1X,3H*19,I2,12F8.0,F10.0)
   97 FORMAT(//33H *   DATA CORRELATED WITH STATION)
   31 FORMAT(1H+,32X,13A6)
   41 FORMAT(2X,2H19,I2,12F8.0,2F10.0)
   39 FORMAT(1X,3H*19,I2,12F8.0,2F10.0)
   37 FORMAT(/6H  AVE.,12F8.0,2F10.0)
      IF(K.EQ.0) GO TO 32
      WRITE(6,13)(R(J),J=1,12)
      WRITE(6,15)(A(J),J=1,12)
      WRITE(6,17)(B(J),J=1,12)
   32 CONTINUE
      WRITE(6,47)
      WRITE(6,49)
      N=1
      DO 19 I=M1,N1
      IF(K.EQ.0) GO TO 29
  106 IF(LL(N).GE.M1) GO TO 104
      N=N+1
      GO TO 106
  104 IF(LL(N).NE.I) GO TO 29
      N=N+1
      Y(I,13)=0.0
      IF(LO.NE.0) GO TO 130
      DO 27 J=1,12
      Y[illegible]A(J)*X(I,J)**B(J)
   27 Y(I,13)=Y(I,13)+Y(I,J)
      C(I,1)=A(13)*X(I,13)**B(13)
      GO TO 134
  130 DO 132 J=1,12
      Y(I,J)=A(J)+X(I,J)*B(J)
  132 Y(I,13)=Y(I,13)+Y(I,J)
      C(I,1)=A(13)+X(I,13)*B(13)
  134 WRITL(6,57) I,(Y(I,J),J=1,13)
      GO TO 19
   29 WRITE(6,53)I,(Y(I,J),J=1,13)
   19 CONTINUE
      T1=N1-M1+1
      DO 43 J=1,13
   43 SUMYC(J)=0.0
      UO 45 J=1,13
      UO 69 I=M1,N1
   69 SUMYC(J)=SUMYC(J)+Y(I,J)
   45 AVEYC(J)=SUMYC(J)/T1
      WRITE(6,55)(AVEYC(J),J=1,13)
      IF(K.EQ.0) GO TO 35
      WRITE(6,97)
      WRITE(6,31)NAME4
   35 CONTINUE
      WRITE(6,21)T1
  156 FORMAT(1H+,30X,18HLINEAR REGRESSION  )
  158 FORMAT(1H+,30X,18HLOG-LOG REGRESSION )
      IF(NSC.EQ.1) GO TO 154
      IF(LO.NE.0) GO TO 150
  152 WRITE(6,158)
      GO TO 154
  150 WRITE(6,156)
  154 IF(NSP.EQ.1) GO TO 99
      WRITE(6,33)NAME2
      IF(K.EQ.0) GO TO 70
      WRITE(6,58)(R(J),J=1,13)
      WRITE(6,59)(A(J),J=1,13)
      WRITE(6,60)(B(J),J=1,13)
   70 CONTINUE
      WRITE(6,47)
      WRITE(6,49)
      N=1
      DO 90 I=M2,N2
      IF(K.EQ.0) GO TO 88
  112 IF(LL(N).GE.M2) GO TO 116
      N = N+1
      GO TO 112
  116 IF (LL(N).NE.I) GO TO 88
      N=N+1
      Y(I,13)=0.0
      C(I,1)=0.0
      IF(LO.NE.0) GO TO 140
      DO 91 J=1,12
      Y(I,J)=A(J)*X(I,J)**B(J)
   91 Y(I,13)=Y(I,13)+Y(I,J)
      C(I,1)=A(13)*X(I,13)**B(13)
      GO TO 144
  140 DO 142 J=1,12
      Y(I,J)=A(J)+X(I,J)*B(J)
  142 Y(I,13)=Y(I,13)+Y(I,J)
      C(I,1)=A(13)+X(I,13)*B(13)
  144 WRITE(6,39) I,(Y(I,J),J=1,13),C(I,1)
      GO TO 90
   88 WRITE(6,41)I,(Y(I,J),J=1,13),C(I,1)
   90 CONTINUE
      T2=N2-M2+1
      DO 92 J=1,13
   92 SUMYC(J)=0.0
      DO 96 J=1,13
      DO 94 I=M2,N2
   94 SUMYC(J)=SUMYC(J)+Y(I,J)
   96 AVEYC(J)=SUMYC(J)/T2
      SUMCC=0.0
      DO 93 I=M2,N2
   93 SUMCC=SUMCC+C(I,1)
      AVECC=SUMCC/T2
      WRITE(6,37)(AVEYC(J),J=1,13),AVECC
      IF(K.EQ.0) GO TO 71
      WRITE(6,97)
      WRITE(6,31)NAME4
   71 CONTINUE
      WRITE(6,21)T2
  166 FORMAT(1H+,30X,18HLINEAR REGRESSION  )
  168 FORMAT(1H+,30X,18HLOG-LOG REGRESSION )
      IF(NSC.EQ.1) GO TO 164
      IF(LO.NE.0) GO TO 160
  162 WRITE(6,168)
      GO TO 164
  160 WRITE(6,166)
  164 IF(NP.EQ.0) GO TO 99
      WRITE(7,23)NAME2
   23 FORMAT(1H ,13A6)
   30 FORMAT(4X,I4,12I6)
      DIMENSION INTY(13)
      DO 89 I=M2,N2
      DO 66 J=1,12
   66 INTY(J)=Y(I,J)+0.5
   89 WRITE(7,30) I,(INTY(J),J=1,12)
   99 CONTINUE
      GO TO 95
      STOP
      END
```

Sample Output

HISTORICAL AND ESTIMATED RUNOFF OF 9-2275 WEST FORK BEAVER CREEK NEAR LONETREE, WYOMING FOR PERIOD 1931-66

```
   R       .930    .920    .894    .744    .789    .760    .929    .961    .984    .986    .980    .977                .974
   A       .408    .582    .219    .086    .073    .587    .074   3.217   6.803   2.182    .754    .427               2.049
   B      1.100   1.053   1.219   1.382   1.432   1.045   1.402    .800    .739    .895   1.026   1.109                .860

 WATER
  YEAR     OCT     NOV     DEC     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP   ANNUAL
 *1931    575.    413.    285.    202.    154.    187.    268.   1438.   1424.    549.    605.    308.    6407.    6825.
 *1932    375.    321.    241.    183.    165.    187.    298.   3237.   4559.   2065.   1187.    449.   13269.   13700.
 *1933    375.    275.    187.    183.    154.    171.    207.   1348.   4187.   1568.    560.    258.    9472.    9764.
 *1934    287.    275.    215.    161.    137.    151.    408.   1199.    656.    191.    656.    258.    4594.    4700.
 *1935    331.    275.    215.    183.    154.    187.    268.   1139.   5238.   1199.    605.    589.   10383.   10977.
 *1936    331.    275.    241.    183.    154.    171.    268.   2143.   2061.   1322.   1421.   1042.    9612.    9300.
 *1937    416.    457.    241.    183.    154.    171.    326.   3579.   3612.   1900.   1187.    701.   12926.   13296.
 *1938    416.    321.    187.    183.    154.    187.    485.   2722.   5407.   1941.   1057.    969.   14029.   14440.
 *1939    827.    670.    304.    202.    168.    202.    583.   3692.   1759.    710.      8.    620.    9785.   10426.
  1940    430.    250.    170.    150.    130.    160.    370.   3200.   1500.    420.    330.    660.    7770.    7770.
  1941    800.    370.    260.    210.    130.    160.    280.   3400.   4700.   2500.   1300.    680.   14790.   14790.
  1942    600.    460.    350.    230.    170.    190.    250.   2300.   4600.   2000.    660.    440.   12250.   12250.
  1943    360.    320.    270.    210.    160.    260.   1200.   2600.   3100.   2000.   1000.    420.   11900.   11900.
  1944    370.    310.    240.    170.    180.    210.    300.   2500.   4600.   2800.    800.    380.   12860.   12860.
  1945    440.    270.    160.    150.    140.    170.    200.   1800.   3700.   3500.   1900.    710.   13140.   13140.
  1946    440.    400.    290.    220.    170.    210.   1400.   2200.   2800.   1100.    620.    300.   10150.   10150.
  1947    320.    280.    230.    110.    110.    170.    260.   3700.   3900.   3000.   1400.    770.   14250.   14250.
  1948    680.    470.    300.    230.    180.    180.    350.   3800.   2800.    630.    600.    370.   10590.   10590.
  1949    373.    323.    222.    160.    139.    160.    442.   2090.   5190.   2490.    893.    399.   12881.   12881.
  1950    559.    439.    305.    215.    167.    200.    456.   1900.   3460.   1900.    781.    511.   10893.   10893.
  1951    247.    206.    201.    169.    139.    154.    241.   1670.   3480.   2330.   1330.    506.   10673.   10673.
  1952    499.    323.    246.    188.    167.    263.    614.   3680.   6200.   3010.   1550.    655.   17395.   17395.
  1953    509.    400.    246.    215.    167.    246.    447.   1110.   6240.   1770.    921.    337.   12608.   12608.
  1954    277.    316.    241.    154.    111.    149.    423.   1690.   1210.   1210.    529.    507.    6817.    6817.
  1955    297.    234.    192.    154.    139.    166.    231.   1690.   2740.    992.    739.    451.    8025.    8025.
  1956    374.    292.    227.    215.    184.    206.    374.   2060.   2400.   1070.    420.    236.    8058.    8058.
  1957    265.    184.    154.    154.    128.    144.    198.   1100.   8030.   4350.   1690.    584.   16981.   16981.
  1958    429.    285.    246.    215.    167.    184.    270.   3780.   3270.   1030.    757.    665.   11298.   11298.
  1959    399.    269.    219.    175.    139.    170.    281.   1390.   4440.   1570.    909.    546.   10507.   10507.
  1960    534.    320.    194.    174.    144.    205.    377.   2430.   4300.   1290.    488.    484.   10940.   10940.
  1961    459.    280.    246.    215.    167.    184.    299.   2110.   2750.   1160.   1440.   1630.   10940.   10940.
  1962   1140.    764.    389.    307.    232.    221.    879.   3080.   5110.   2790.    964.    524.   16400.   16400.
  1963    430.    310.    190.    150.    130.    140.    190.   2100.   2000.   1400.    700.    580.    8320.    8320.
  1964    420.    340.    230.    150.    140.    140.    190.   3300.   5800.   3300.   1100.    500.   15610.   15610.
  1965    360.    330.    310.    270.    200.    190.    350.   1300.   9400.   8100.   3500.   1500.   25810.   25810.
 *1966    856.    494.    218.    168.    130.    234.    636.   2349.   2036.   1753.    905.    770.   10570.   10141.

  AVE.    467.    348.    241.    189.    155.    186.    406.   2356.   3852.   1970.    987.    592.   11746.   11812.

 *   DATA CORRELATED WITH STATION 9-2265  MIDDLE FORK BEAVER CREEK NEAR LONETREE.  WYO.

 NUMBER OF YEARS  36.          LOG-LOG REGRESSION
```

APPENDIX E

Canal Diversions by Year for Each Subbasin Location and Reservoirs Used in Study

Table E-1. Diversions for irrigation within the subbasins of the Green Division (acre-feet/month).

Subbasin	Model Years	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	ac-ft/ac/yr
New Fork River Basin	1964			60,500	92,800	46,200	1,800	1,800			203,100	4.6
	1965			90,200	92,000	38,900	10,600	10,600			242,300	5.5
Green River above LaBarge, Wyoming	1965			45,800	148,200	103,400	35,700	13,700			346,800	3.6
	1966			81,400	89,700	75,000	43,900	32,000			322,000	3.3
Green River above Fontenelle Reservoir	1965			800	5,100	6,800	700				13,400	3.7
	1966			700	4,200	5,700	500				11,100	3.1
Big Sandy Creek	1962			7,600	18,200	14,400	12,100	2,300			54,600	3.9
	1963			7,900	16,900	13,900	9,600	1,000			49,300	3.5
Green River above Green River, Wyoming	1964			2,000	2,000	2,000	2,000	1,000			9,000	6.0
	1965			2,000	2,000	2,000	2,000	1,000			9,000	6.0
Blacks Fork River Basin	1964			33,600	57,000	29,800	10,900	3,800			135,100	2.1
	1965			20,100	51,000	56,500	8,200	8,100			143,900	2.2
Green River above Flaming Gorge Dam	1965			14,900	23,300	29,800	25,100	15,500			108,600	4.6
	1966			19,400	20,800	15,500	9,000	7,100			71,800	3.1
Little Snake River Basin	1965		6,100	45,400	46,100	42,900	3,600	5,400	1,300		150,800	7.0
	1966		5,400	39,600	23,400	5,400	3,100	1,800	1,800		80,500	3.7
Yampa River Basin	1965			12,200	116,700	100,000	25,000	25,000	8,400		287,300	4.3
	1966		10,600	116,700	63,900	53,400	33,300	23,300			301,200	4.5
Green River above Jensen, Utah	1964		1,700	5,800	5,800	3,900	3,900	1,900	400		23,400	5.2
	1965		1,900	5,800	5,800	3,900	3,900	1,900	300		23,500	5.2
Ashley Creek Basin	1964		200	28,200	15,000	14,000	9,200	5,800	3,200		75,600	3.3
	1965			13,400	23,600	18,400	9,600	5,600	2,000	2,000	74,600	3.2
Duchesne River above Duchesne, Utah	1965		900	7,100	14,400	14,300	10,200	4,300	3,000		54,200	5.4
	1966		800	19,600	20,700	11,000	10,300	8,200	6,900		77,500	7.7
Duchesne River above Randlett, Utah	1964		7,000	78,000	81,000	98,000	97,000	64,000	48,000	35,000	508,000	4.2
	1965		23,000	101,000	78,000	82,000	72,000	55,000	43,000	15,000	469,000	3.9
White River Basin	1964		12,200	31,500	57,300	22,900	9,300	12,700	7,800		153,700	5.3
	1965		15,600	57,300	61,500	30,700	26,400	13,200			204,700	7.0
Green River above Ouray, Utah	1964		1,800	13,300	6,500	4,800	2,900	900			30,200	3.2
	1965		2,000	10,700	9,500	6,600	4,900	3,900	2,000		39,600	4.2
Price River Basin	1964		2,200	12,200	9,600	13,100	6,700	6,200	3,300	1,100	54,400	3.3
	1965		4,000	10,700	14,000	11,000	8,700	7,600	3,800	2,900	62,700	3.8
Green River above Green River, Utah	1964		2,000	7,900	5,900	2,900	2,000	1,000			21,700	3.3
	1965		2,100	10,000	7,000	3,900	3,000	1,900	1,100		29,000	4.5
San Rafael River	1964		2,200	42,800	33,100	18,800	7,700	1,900	3,600	3,000	113,100	3.4
	1965		5,000	35,900	29,000	40,600	12,400	16,300	9,700	1,900	150,800	4.6

Preceding page blank

Table E-2. Diversions for irrigation within the subbasins of the Grand division (acre-feet/month).

Subbasin	Model Years	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	ac-ft/ac/yr
Colorado River above Hot Sulphur Springs, Colo.	1965			18,700	22,400	23,600	7,500	7,500	2,000		81,700	3.7
	1966		1,300	26,600	27,900	18,300	11,900	6,600	2,200		94,800	4.3
Eagle River Basin	1965			20,600	56,600	42,300	33,500	18,800	8,300		180,100	8.9
	1966			13,700	40,600	30,400	28,800	13,200	5,100		131,800	6.5
Colorado River above Glenwood Springs, Colo.	1965		16,400	92,000	85,200	97,000	37,200	11,800	6,200		345,800	5.1
	1966		25,400	93,700	103,800	66,600	33,800	28,200	9,600		361,100	5.3
Roaring Fork River Basin	1964			25,600	27,000	29,000	36,700	19,500	5,700		143,500	5.3
	1965		5,200	22,400	27,000	36,300	33,100	5,200	2,700		131,900	4.8
Colorado River above Plateau Creek	1959		7,600	35,700	28,500	5,500	6,300	5,900	4,600		94,100	1.9
	1960		13,400	83,200	50,800	14,700	8,400	9,200			179,700	3.6
Plateau Creek Basin	1963		5,900	17,200	13,100	12,600	11,300	6,700	1,700		68,500	3.4
	1964		500	9,200	17,200	11,600	16,500	9,200			64,200	3.2
Gunnison River above Gunnison, Colorado	1964			57,000	84,800	84,400	23,200	35,400	32,100		316,900	6.3
	1965			53,200	88,600	100,400	32,100	24,100	31,600		330,000	6.5
Gunnison River above North Fork Gunnison River	1964		4,400	13,300	27,800	21,500	16,100	7,900	6,000		97,000	3.0
	1965		4,100	21,000	26,700	32,200	16,900	13,400	3,300	1,100	118,700	3.6
Uncompahgre River Basin	1960	7,200	56,000	184,000	224,000	166,400	127,200	98,400	40,000	1,600	904,800	9.4
	1961	1,600	60,000	192,000	220,000	151,200	128,000	65,600	8,000	1,600	828,000	8.6
Gunnison River above Grand Junction, Colo.	1965		20,600	76,600	110,500	100,800	92,500	55,000	7,700		463,700	7.5
	1966		17,500	95,600	95,600	87,400	70,000	37,500	6,200		409,800	6.6
Colorado River above Colorado-Utah State Line	1964		65,400	94,500	93,200	83,300	85,200	81,300	33,000		535,900	6.8
	1965		58,100	113,000	113,000	120,300	100,400	93,200	34,400		632,400	8.0
San Miguel River Basin	1964	1,900	1,900	8,600	21,600	16,600	10,100	10,100	1,500		72,300	2.9
	1965	1,900	14,700	19,300	18,900	9,200	8,400	2,300			74,700	3.0
Dolores River Basin	1964		1,600	10,700	7,300	5,000	3,800	3,700			32,100	2.2
	1965			5,600	11,800	10,700	7,000	4,400	1,100	400	41,000	2.8
Colorado River above Cisco, Utah	1964		500	2,500	2,500	2,500	2,000	1,000			11,000	4.4
	1965		500	2,300	2,500	2,500	2,000	1,000			10,800	4.3

Table E-3. Diversions for irrigation within the subbasin of the San Juan division (acre-feet/month).

Subbasin	Model Years	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total	ac-ft/ac/yr
San Juan River above	1964			12,700	19,600	13,200	10,600	7,600	4,100		67.800	6.8
Arboles, Colorado	1965			5,200	12,900	13,800	7,600	7,200	4,300		51,000	5.1
San Juan River above	1964			44,200	48,800	45,100	43,300	34,700	19,600		235,700	4.3
Archuleta, New Mexico	1965			17,300	41,500	45,100	42,900	35,100	19,600		201,500	3.7
Animas River Basin	1962		15,700	38,100	33,800	31,500	32,400	18,800	7,300		177,600	6.3
	1963		6,800	39,000	23,000	25,100	23,300	15,700	8,900		141,800	5.0
San Juan River above	1964		2,500	7,900	10,700	11,100	8,200	6,400	2,100		48,900	4.7
Farmington, N.M.	1965		2,500	7,900	10,700	11,100	8,200	6,400	2,100		48,900	4.7
LaPlata River Basin	1961	700	8,900	23,700	6,700	2,200			1,100		43,300	1.7
	1962		11,900	14,500	7,600	3,900	2,200	1,100			41,200	1.6
San Juan River above	1964		3,800	11,200	15,100	12,200	9,100	7,100	7,000		65,500	5.3
Shiprock, N.M.	1965		3,800	11,200	15,100	12,200	9,100	7,100	7,000		65,500	5.3
San Juan River above	1964		17,400	88,300	78,200	32,600	33,200	5,600	2,800		258,100	3.8
Bluff, Utah	1965			45,000	100,100	68,100	43,900	16,900	6,200		280,200	4.2
Colorado River above	1964		13,800	26,800	27,100	22,900	17,100	11,500	9,700		128,900	3.4
Lee's Ferry, Arizona	1965		12,900	33,800	36,800	30,000	14,700	19,100	16,200	5,000	168,500	4.4

Table E-4. Location and usable capacities of reservoirs in Green Division.

Subbasin	Reservoir Name	Usable Capacity acre-feet	Tributary Location	Latitude	Longitude
New Fork River Basin					
	New Fork Lake	45,900	New Fork River	43°05'	109°58'
	Willow Lake	15,120	Lake Creek	43°00'	109°54'
	Fremont Lake	20,600	Pine Creek	42°52'	109°50'
	Boulder Lake	16,207	Boulder Creek	42°50'	109°34'
	Silver Lake	2,150	Silver Creek	42°48'	109°24'
Green River above LaBarge, Wyoming					
	Middle Piney Lake	4,200	Middle Piney Creek	42°36'	110°34'
	Sixty Seven Reservoir	4,330	North Piney Creek	42°36'	110°12'
Green River above Fontenelle Reservoir					
	Fontenelle Reservoir	344,800	Green River	42°02'	110°04'
Big Sandy Creek Basin					
	Black Joe Lake Reservoir	1,100	Big Sandy Creek	42°39'	109°10'
	Big Sandy Reservoir	38,500	Big Sandy Creek	42°15'	109°26'
	Elkhorn Reservoir	1,450	Little Sandy Creek	42°38'	109°07'
	Eden Reservoir No. 1	16,000	Little Sandy Creek	42°15'	109°23'
	Pacific No. 2	1,400	Pacific Creek	42°18'	109°01'
Green River above Green River, Wyoming					
	No Storage				
Black Fork River Basin					
	Patterson Lake	1,870	Blacks Fork	41°22'	110°20'
	Uinta Reservoir No. 3	2,000	Blacks Fork	41°13'	110°40'
	Lake Viva Naughton	28,000	Hams Fork	41°57'	110°39'
	Kemmer Reservoir	1,080	Hams Fork	41°48'	110°33'
	Piedmount Reservoir	1,090	Big Muddy Creek	41°12'	110°41'
Green River above Flaming Gorge Dam					
	Hoop Lake	3,920	Beaver Creek	40°55'	110°07'
	Beaver Meadow Reservoir	1,790	Burnt Fork	40°53'	110°04'
	Flaming Gorge Reservoir	3,516,000	Green River	45°55'	109°25'22"
Little Snake River Basin					
	Savery Reservoir[a]	18,200	Savery Creek	41°14'	107°22'
	Pot Hook Reservoir[a]	58,000	Slater Creek	41°00'	107°23'
Yampa River Basin					
	Stillwater Reservoir	6,200	Bear River	40°02'	107°09'
	Grander Reservoir	1,165	Bear River	40°03'	107°02'
Green River above Jensen, Utah					
	Warner Reservoir	1,520	Pot Creek	40°47'	109°17'
	Grouse Reservoir	2,480	Pot Creek	40°43'	109°10'
Ashley Creek Basin					
	Steinaker Reservoir	38,090	Diversion from Brush Creek	40°32'	109°32'

[a] Under construction as of January 1, 1966.

Table E-4. Continued.

Subbasin	Reservoir Name	Usable Capacity acre-feet	Tributary Location	Latitude	Longitude
Duchesne River above Duchesne, Utah					
	Strawberry Reservoir	270,000	Strawberry River	40°10'10''	111°10'45''
	Red Creek Reservoir	6,500	Red Creek	40°20'	110°47'
Duchesne River above Randlett, Utah					
	Kidney Lake	3,900	Brown Duck Creek	40°35'	110°37'
	Brown Duck Lake	3,720	Brown Duck Creek	40°35'	110°36'
	Moon Lake Reservoir	35,800	Lake Fork	40°33'40	110°29'30''
	Twin Pots Lake	3,900	Lake Fork	40°30'	110°28'
	Fox Lake	1,200	Shale Creek	40°47'	110°10'
	Lake Atwood	2,700	Lake Atwood Creek	40°45'	110°18'
	John Starr Reservoir	2,370	Uinta River	40°32'	110°08'
	Paradise Park Reservoir	3,100	Paradise Creek	40°40'	109°56'
	Montez Creek Reservoir	1,260	Uinta River	40°20'	109°58'
White River Basin					
	No Large Reservoirs				
Green River above Ouray, Utah					
	Oak Park Reservoir	6,250	Big Brush Creek	40°45'	109°36'
	East Park	1,300	Little Brush Creek	40°46'	109°31'
Price River Basin					
	Fairview Reservoir	1,900	Gooseberry Creek	39°37'	111°17'
	Scofield Reservoir	65,780	Price River	39°47'	111°08'
	Desert Lake	7,300	Price River	39°24'	110°46'
	Olsen Lake	3,500	Price River	39°27'	110°43'
Green River above Green River, Utah					
	No Large Reservoirs				
San Rafael River Basin					
	Huntington Creek Reservoir	4,410	Huntington Creek	39°37'	111°15'
	Cleveland Reservoir	2,310	Huntington Creek	39°34'	111°14'
	Miller Flat Reservoir	5,560	Huntington Creek	39°33'	111°16'
	Ferron Reservoir	1,200	Indian Creek	39°07'	111°27'
	Joes Valley Reservoir	54,610	Cottonwood Creek	39°37'10''	111°16'10''

Table E-5. Location and usable capacities of reservoirs in Grand Division.

Subbasin	Reservoir Name	Usable Capacity acre-feet	Tributary Location	Latitude	Longitude
Colorado River above Hot Sulphur Springs, Colorado					
	Shadow Mountain Reservoir	17,860	Colorado River	40°12'	105°50'
	Lake Granby	465,600	Colorado River	40°11'	105°52'
	Willow Creek Reservoir	9,060	Willow Creek	40°09'	105°56'
Eagle River Basin					
	Robinson Reservoir	2,520	Eagle River	39°24'	106°15'
Colorado River above Glenwood Springs, Colorado					
	Williams Fork Reservoir	96,820	Williams River	40°02'	106°12'
	Troublesome Reservoir	1,070	Troublesome Creek	40°17'	106°17'
	Barber Reservoir	4,290	Muddy Creek	40°18'	106°30'
	McMahon Reservoir	4,500	Red Dirt Creek	40°11'	106°35'
	Dillon Reservoir	254,000	Blue River	39°38'	106°04'
	Green Mountain Reservoir	146,900	Blue River	39°53'	106°15'
Roaring Fork River Basin					
	Ivanhoe Reservoir	1,400	Frying Pan River	39°16'	106°30'
	Spring Creek Reservoir	2,800	Cattle Creek	39°26'	107°05'
Colorado River above Plateau Creek					
	Harvey Gap Reservoir	5,800	Unnamed Creek	39°37'	107°40'
	Rifle Gap Reservoir[a]	10,900	West Rifle Creek	39°38'	107°48'
Plateau Creek Basin					
	Leon Lake	3,000	Leon Creek	39°04'	107°48'
	Big Creek No. 1	2,700	Big Creek	39°04'	107°58'
	Bonham Reservoir	1,800	Big Creek	39°06'	107°55'
	Atkinson Reservoir	1,500	Atkinson Creek	39°06'	107°52'
	Vega Reservoir	32,930	Plateau Creek	39°13'30"	107°48'40"
	Cottonwood Lake	2,800	Cottonwood Creek	39°05'	107°58'
Gunnison River above Gunnison, Colorado					
	Taylor Park Reservoir	106,200	Taylor River	38°49'05"	106°36'15"
	Lake San Cristobal	9,800	Lake Fork	37°59'	107°17'
Gunnison River above North Fork Gunnison River					
	Soap Creek Park Reservoir[a]	47,000	Soap Creek	38°28'	107°17'
	Blue Mesa Reservoir	748,000	Gunnison River	38°27'	107°20'
	Silver Jack Reservoir[a]	11,200	Cimmeron Creek	38°16'	107°35'
	Gould Reservoir	6,420	Iron Creek	38°35'	107°35'
	Crawford Reservoir	13,500	Iron Creek	38°41'	107°37'
	Fruitland Reservoir	9,511	Smiths Fork	38°40'	107°45'
	Crystal Reservoir[a]	16,430	Gunnison River	38°33'	107°37'
	Morrow Point Reservoir[a]	42,120	Gunnison River	38°37'	107°33'

[a] Under construction as of January 1, 1966.

Table E-5. Continued.

Subbasin	Reservoir Name	Usable Capacity acre-feet	Tributary Location	Latitude	Longitude
Uncompahgre River Basin	No Large Reservoirs				
Gunnison River above Grand Junction, Colorado	Overland Reservoir	2,660	Cow Creek	39°04'	107°39'
	Paonia Reservoir	18,300	Muddy Creek	38°57'	107°20'
	Island Lake	1,100	Ward Creek	39°03'	108°00'
	Deep Ward Lake	1,400	Ward Creek	39°02'	107°59'
	Baron Lake	1,000	Kiser Creek	39°02'	107°58'
	Eggleston Lake	2,700	Kiser Creek	39°02'	107°55'
	Fruitgrowers Reservoir	6,400	Alfalfa Ditch	38°49'	107°55'
	Trickel Park Lake	3,200	Surface Creek	39°02'	107°52'
Colorado River above Colorado-Utah State Line	No Large Reservoirs				
San Miguel River Basin	Lake Hope	2,300	Lake Fork	37°47'	107°51'
	Trout Lake	2,700	Lake Fork	37°50'	107°54'
	Gurley Reservoir	8,800	Naturita Creek	38°03'	108°15'
	Lone Cone Reservoir	1,800	Naturita Creek	38°00'	108°15'
Dolores River Basin	Ground Hog Reservoir	21,700	Beaver Creek	37°46'	108°17'
	Buckeye Reservoir	3,000	West Paradox Creek	38°25'	109°02'
Colorado River above Cisco, Utah	No Large Reservoirs				

Table E-6. Location and usable capacities of reservoirs in San Juan Division.

Subbasin	Reservoir Name	Usable Capacity acre-feet	Tributary Location	Latitude	Longitude
San Juan River above Arboles, Colorado					
	No Large Reservoirs				
San Juan River above Archuleta, New Mexico					
	Williams Creek Reservoir	1,080	Piedra River	37°37'	107°10'
	Vallecito Reservoir	126,300	Los Pinos River	37°23'00"	107°34'30"
	Navajo Reservoir	1,036,000	San Juan River	36°48'35"	107°36'35"
Animas River Basin					
	Lemon Reservoir	40,100	Florida River	37°22'	107°38'
	Electra Lake	21,000	Cascade Creek	37°38'	107°47'
San Juan River above Farmington, New Mexico					
	No Large Reservoirs				
LaPlata River Basin					
	No Large Reservoirs				
San Juan River above Shiprock, New Mexico					
	Juans Lake	5,000	Chaco River	36°05'	108°11'
	Captain Toms Reservoir	1,730	Chaco River	36°16'	108°40'
San Juan above Bluff, Utah					
	Jackson Gulch Reservoir	10,000	Mancos River	37°23'	108°16'
	Beaver Lake	1,070	Mancos River	37°23'	108°18'
	Summit Reservoir	4,800	Diversion from Dolores River	37°25'	108°24'
	Narraguinepp Reservoir	19,300	Diversion from Dolores River	37°28'	108°36'
	Wheat Fields Reservoir	1,000	Chinle Wash	36°12'	109°05'
	Many Farms Reservoir	25,000	Chinle Wash	36°21'	109°35'
	Lower Rock Point Reservoir	1,000	Chinle Wash	36°28'	109°26'
	Marsh Pass Reservoir	1,160	Chinle Wash	36°37'	110°28'
Colorado River above Lee's Ferry, Arizona					
	Fish Lake	4,000	Fremont River	38°33'	111°42'
	Johnson Reservoir	5,680	Fremont River	38°35'	111°37'
	Forsythe Reservoir	3,400	Fremont River	38°32'	111°32'
	Mill Meadow Reservoir	5,200	Fremont River	38°30'	111°34'
	Bowns Reservoir	3,150	Oak Creek	38°07'	111°16'
	Valley City Reservoir	1,700	Salt Valley Wash	38°52'	109°47'
	Spectale Reservoir	1,250	Escalante	38°05'	111°30'
	Lake Powell	20,876,000	Colorado River	36°56'25"	111°27'10"

APPENDIX F

Vegetative Distributions and Acreages of Each Subbasin
k_c Values for Crops and Phreatophytes

BLANK PAGE

Table F-1. Vegetative distribution and acreages associated with subbasins in the Green Division.

Subbasin	Crop									Crop Acreage	Phreatophyte Acreage
	Clover	Alfalfa	Pasture	Grain	Sugar Beets	Potatoes	Orchard	Corn, maze & sorghum	Small truck		
New Fork River Basin	23%	5%	71%	1%	-	-	-	-	-	44,000	4,000
Green River above LaBarge, Wyoming	30%	5%	64%	1%	-	-	-	-	-	97,500	20,000
Green River above Fontenelle Reservoir	10%	15%	55%	20%	-	-	-	-	-	3,600	0
Big Sandy Creek Basin	25%	50%	10%	15%	-	-	-	-	-	18,000	4,500
Green River above Green River, Wyoming	8%	27%	50%	15%	-	-	-	-	-	1,500	2,300
Blacks Fork River Basin	25%	15%	53%	7%	-	-	-	-	-	65,500	8,000
Green River above Flaming Gorge Dam	41%	15%	42%	2%	-	-	-	-	-	23,500	5,000
Little Snake River Basin	30%	31%	29%	10%	-	-	-	-	-	21,600	4,500
Yampa River Basin	68%	13%	20%	1%	-	-	-	-	-	66,700	12,000
Green River above Jensen, Utah	31%	50%	12%	7%	-	-	-	-	-	4,500	6,000
Ashley Creek Basin	5%	45%	18%	25%	-	-	-	7%	-	23,000	7,000
Duchesne River above Duchesne, Utah	11%	78%	41%	18%	-	-	-	2%	-	15,000	4,500
Duchesne River above Randlett, Utah	6%	55%	19%	15%	-	-	-	5%	-	118,500	17,500
White River Basin	29%	27%	34%	10%	-	-	-	-	-	29,200	3,800
Green River above Ouray, Utah	-	53%	16%	22%	-	-	-	9%	-	9,500	4,250
Price River Basin	2%	60%	10%	18%	3%	-	1%	6%	-	16,500	1,500
Green River above Green River, Utah	1%	64%	5%	3%	-	-	6%	15%	6%	6,500	12,000
San Rafael River Basin	3%	65%	4%	17%	-	-	1%	10%	-	33,000	6,000

Preceding page blank

Table F-2. Vegetative distribution and acreages associated with subbasins in the Grand Division.

Subbasin	Crop									Crop Acreage	Phreatophyte Acreage
	Clover	Alfalfa	Pasture	Grain	Sugar Beets	Potatoes	Orchard	Corn, maze & sorghum	Small truck		
Colorado River above Hot Sulphur Springs, Colorado	82%	4%	13%	1%	-	-	-	-	-	22,000	3,150
Eagle River Basin	39%	47%	6%	8%	-	-	-	-	-	20,300	2,400
Colorado River above Glenwood Springs, Colorado	84%	3%	11%	2%	-	-	-	-	-	67,700	5,560
Roaring Fork River Basin	32%	50%	4%	9%	-	-	-	5%	-	27,200	2,130
Colorado River above Plateau Creek	4%	69%	8%	13%	-	-	-	6%	-	50.400	7,230
Plateau Creek Basin	3%	40%	48%	7%	-	-	-	2%	-	20,200	2,000
Gunnison River above Gunnison, Colorado	56%	2%	43%	1%	-	-	-	-	-	50,600	9,500
Gunnison River above North Fork Gunnison River	29%	20%	40%	11%	-	-	-	-	-	32,700	2,500
Uncompahgre River Basin	10%	32%	10%	22%	4%	-	2%	10%	10%	96,000	8,000
Gunnison River above Grand Junction, Colorado	3%	35%	9%	17%	3%	-	12%	18%	3%	61,700	13,900
Colorado River above Colorado-Utah State Line	3%	37%	6%	9%	10%	-	12%	21%	2%	79,300	18,460
San Miguel River Basin	10%	40%	19%	22%	-	-	2%	7%	-	25,200	4,000
Dolores River Basin	13%	53%	9%	19%	-	-	-	6%	-	14,600	7,000
Colorado River above Cisco, Utah	1%	60%	7%	4%	-	-	6%	20%	2%	2,500	3,000

Table F-3. Vegetative distribution and acreages associated with subbasins in the San Juan Division

Subbasin	Crop									Crop Acreage	Phreatophyte Acreage
	Clover	Alfalfa	Pasture	Grain	Sugar Beets	Potatoes	Orchard	Corn, maze & sorghum	Small truck		
San Juan River above Arboles, Colorado	60%	19%	9%	10%	-	-	-	2%	-	10,000	3,000
San Juan River above Archuleta, New Mexico	17%	25%	36%	20%	-	-	-	2%	-	54,700	8,700
Animas River Basin	19%	44%	6%	26%	-	-	-	5%	-	28,200	7,400
San Juan River above Farmington, New Mexico	1%	49%	8%	11%	-	-	7%	19%	5%	10,400	3,700
LaPlata River Basin	15%	53%	3%	22%	-	-	1%	5%	1%	26,000	2,100
San Juan River above Shiprock, New Mexico	-	60%	2%	5%	-	-	6%	23%	4%	12,300	1,800
San Juan River above Bluff, Utah	10%	50%	9%	14%	-	-	2%	13%	2%	67,500	0
Colorado River above Lee's Ferry, Arizona	4%	66%	6%	17%	-	2%	1%	3%	1%	38,300	11,700

Table F-4. Crop coefficients utilized in computation of potential consumptive use.

Month	Clover	Alfalfa	Pasture	Grain	Sugar Beets	Potatoes	Orchard	Corn, maze & sorghum	Small truck	Phreatophytes
Jan.	0.51	0.68	0.49	0.25	0.40	0.25	0.17	0.40	0.28	0.65
Feb.	0.61	0.80	0.58	0.25	0.40	0.25	0.25	0.40	0.28	0.80
Mar.	0.76	0.88	0.73	0.25	0.40	0.25	0.39	0.40	0.28	1.15
Apr.	0.89	1.00	0.85	0.26	0.42	0.25	0.63	0.40	0.30	1.35
May	0.95	1.08	0.90	0.50	0.45	0.25	0.86	0.48	0.35	1.40
June	0.97	1.12	0.92	1.54	0.66	0.38	0.96	0.64	0.62	1.40
July	0.97	1.10	0.92	1.12	1.10	0.90	0.95	0.98	0.82	1.40
Aug.	0.96	1.08	0.91	0.25	1.25	1.32	0.81	1.08	0.76	1.40
Sept.	0.90	1.00	0.86	0.25	1.04	1.32	0.54	1.02	0.39	1.35
Oct.	0.83	0.92	0.79	0.25	0.60	0.25	0.30	0.40	0.28	1.25
Nov.	0.70	0.80	0.67	0.25	0.40	0.25	0.19	0.40	0.28	1.00
Dec.	0.57	0.68	0.54	0.25	0.40	0.25	0.16	0.40	0.28	0.75

APPENDIX G

Digital Program, Sample Output, and Mathematical Models for Estimating Average Water Flow Rates and Salinity Concentrations (Monthly and Annual)

Program for Estimating Mean Monthly Averages, Water Flow Rates, and Salinity Concentrations

```
WI FOR QTDS
C     PROGRAM FOR COMPUTING THE AVERAGE MONTHLY DISCHARGE, THE AVERAGE TOTAL
C     DISSOLVED SALT BASED ON THE TIME PERIOD ONLY, AND THE WEIGHTED AVERAGE
C     TOTAL DISSOLVED SALT BASED ON THE TIME PERIOD AND THE DISCHARGE.
C     THIS PROGRAM CAN HANDLE ANY NUMBER OF BASINS WITH ANY NUMBER OF
C     STATIONS WITH ANY NUMBER OF DATA.  BY CHANGING THE DIMENSION.
C     NBAS WHICH IS THE NUMBER OF BASINS. NSTA THE NUMBER OF STATIONS.
C     AND JJ THE NUMBER OF DATA
C     Q AND TDS MUST BE READINGS OF ONE INDIVIDUAL DAY NOT THE AVERAGE FOR A
C     PERIOD OF TIME.
C     QAVE= MONTHLY AVERAGE DISCHARGE
C     ATDST= MONTHLY AVERAGE TDS BASED ON TIME ONLY
C     ATDSQT= MONTHLY AVERAGE TDS BASED ON TIME AND DISCHARGE
C     QANAV= ANNUAL AVERAGE DISCHARGE
C     TDSAAT= ANNUAL AVERAGE TDS BASED ON TIME ONLY
C     TDSAQT= ANNUAL WEIGHTED AVERAGE TDS
      INTEGER DES
      DIMENSION YEAR(800),AMONTH(800),DAY(800),HALP(800),HALPP(800),
     1PERD(800),Q(800),TDS(800),WDAY(3),QAVE(300),TDSTAV(300),
     2TDSQTA(300),TIME(300),QANAV(50),TDSAWA(50),STATIO(16),
     3OLS(10),AZ(300,3),CON(50),ZP(50),AT(21,20)
      DOUBLE PRECISION CON,ZP,AT
      COMMON AZ,ZP,AT
      READ(5,5931)NBAS
 5931 FORMAT(I9)
      DO 9997 NB=1,NBAS
      READ(5,5003)NSTA
 5003 FORMAT(I9)
      DO 9999 NS=1,NSTA
      NT=0
      NA=0
      SUMDAY=0.
      QANTO=0.
      TDSTO=0.
      TDSTQT=0.
      READ(5,5004)(STATIO(IM),IM=1,16)
 5004 FORMAT(16A5)
      WRITE(6,5005)(STATIO(IM),IM=1,16)
 5005 FORMAT(1H0,16A5)
      WRITE(6,9115)
 9115 FORMAT(52X,52HMONTHLY AVERAGES                              ANNUAL AVERAGE
     1)
      WRITE(6,5092)
 5092 FORMAT(6X,105H    DATE              Q          TDS         QAVE
     1ATDST      ATDSQT        QANAV       TDSAAT       TDSAQT)
      READ(5,5006)JJ
 5006 FORMAT(I9)
      YEAR(1)=-99.
      YEAR(JJ+2)=1000.
      SUMQS=0.
      SUMTS=0.
      SUMQ=0.
      NK=JJ+1
      DO 9900 I=2,NK
      READ(5,5007) MONTH,KDAY,KYEAR,Q(I),TDS(I)
 5007 FORMAT(3I2,F9.2,F10.2)
      AMONTH(I) = MONTH
      DAY(I) = KDAY
 9900 YEAR(I) = KYEAR
      DO 9988 I=2,NK
      IF((YEAR(I)-YEAR(I-1)).GT.1.) GO TO 1010
      IF((YEAR(I)-YEAR(I-1))-1.)1975,1020,1975
 1975 IF((AMONTH(I)-AMONTH(I-1)).GT.1.) GO TO 1005
      IF((AMONTH(I)-AMONTH(I-1))-1.)1976,1000,1976
 1976 HALP(I)=(DAY(I)-DAY(I-1))/2
 1012 IF((YEAR(I+1)-YEAR(I)).GT.1.) GO TO 1051
      IF((YEAR(I+1)-YEAR(I))-1.)1972,1025,1972
 1972 IF((AMONTH(I+1)-AMONTH(I)).GT.1.) GO TO 1006
      IF((AMONTH(I+1)-AMONTH(I))-1.)1973,3000,1973
 1973 HALPP(I)=(DAY(I+1)-DAY(I))/2.
 4000 PERD(I)=HALP(I)+HALPP(I)
      SUMQS=SUMQS+Q(I)*TDS(I)*PERD(I)
      SUMTS=SUMTS+TDS(I)*PERD(I)
      SUMQ=SUMQ+Q(I)*PERD(I)
      GO TO 7000
 1000 KKK=AMONTH(I)
      CALL AADAY(KKK,I,WDAY)
      HALP(I) = (DAY(I)+WDAY(1)-DAY(I-1))/2.
      IF(HALP(I).LT.DAY(I)) GO TO 1014
 1005 HALP(I)=DAY(I)
      GO TO 1012
 1014 TT=DAY(I)-HALP(I)
      IF(DAY(I)-1.) 1018,1019,1018
 1018 SUMQS=TT*Q(I-1)*TDS(I-1)
      SUMTS=TT*TDS(I-1)
      SUMQ=TT*Q(I-1)
      GO TO 1012
 1019 SUMQS=TT*Q(I)*TDS(I)
      SUMTS=TT*TDS(I)
      SUMQ=TT*Q(I)
      GO TO 1012
 3000 KKK=AMONTH(I)
      CALL AADAY(KKK,I,WDAY)
      HALPP(I) =(WDAY(2)+DAY(I+1)-DAY(I))/2.
      IF(HALPP(I).GT.DAY(I+1)) GO TO 5000
 1006 KKK=AMONTH(I)
      CALL AADAY(KKK,I,WDAY)
      HALPP(I) = WDAY(2)-DAY(I)
      GO TO 6000
 5000 PERIOD = WDAY(2)-(DAY(I)+HALPP(I))
      SUMQS=SUMQS+Q(I+1)*TDS(I+1)*PERIOD
      SUMTS=SUMTS+TDS(I+1)*PERIOD
      SUMQ=SUMQ+Q(I+1)*PERIOD
      GO TO 6000
 1051 KKK=AMONTH(I)
      CALL AADAY(KKK,I,WDAY)
      HALPP(I) = WDAY(2)-DAY(I)
 6000 PERD(I)=HALP(I)+HALPP(I)
      SUMQS = SUMQS+Q(I)*TDS(I)*PERD(I)
      SUMTS=SUMTS+TDS(I)*PERD(I)
      SUMQ=SUMQ+Q(I)*PERD(I)
      NT=NT+1
      QAVE(NT) = SUMQ/WDAY(2)
      TDSQTA(NT) = SUMQS/(QAVE(NT)*WDAY(2))
      TDSTAV(NT) = SUMTS/WDAY(2)
      TIME(NT) = AMONTH(I)
      SUMDAY=SUMDAY+WDAY(2)
      QANTO = QANTO+WDAY(2)*QAVE(NT)
      TDSTO = TDSTO+WDAY(2)*TDSTAV(NT)
      TDSTQT=TDSTQT+WDAY(2)*QAVE(NT)*TDSTAV(NT)
      GO TO 8000
 7000 KDAY=DAY(I)
      KYEAR = YEAR(I)
      MONTH = AMONTH(I)
      WRITE(6,9000) MONTH,KDAY,KYEAR,Q(I),TDS(I)
 9000 FORMAT(6X,3I3,2F12.2)
      GO TO 9988
 8000 MONTH = AMONTH(I)
      KDAY = DAY(I)
      KYEAR = YEAR(I)
      IF((YEAR(I+1)-YEAR(I)).GT.0.) GO TO 9111
      WRITE(6,1001) MONTH,KDAY,KYEAR,Q(I),TDS(I), AVE(NT),
     1TDSTAV(NT),TDSQTA(NT)
 1001 FORMAT(6X,3I3,5F12.2)
      GO TO 9112
 9111 NA=NA+1
      QANAV(NA) = QANTO/SUMDAY
      TDSAAT = TDSTO/SUMDAY
      TDSAWA(NA) = TDSTQT/(SUMDAY*QANAV(NA))
      WRITE(6,9113) MONTH,KDAY,KYEAR,Q(I),TDS(I),QAVE(NT),
     1TDSTAV(NT),TDSQTA(NT),QANAV(NA),TDSAAT,TDSAWA(NA)
 9113 FORMAT(6X,3I3,8F12.2)
 9112 IF((YEAR(I+1)-YEAR(I)).LE.0.) GO TO 9118
      SUMDAY=0.
      QANTO=0.
      TDSTO=0.
      TDSTQT=0.
 9118 WRITE(6,1002)
 1002 FORMAT(1H )
      SUMQS=0.
      SUMTS=0.
      SUMQ=0.
      GO TO 9988
 1010 HALP(I)=DAY(I)
      GO TO 1012
 1020 IF((AMONTH(I)-AMONTH(I-1))+11.)1010,1000,1010
 1025 IF((AMONTH(I+1)-AMONTH(I))+11.)1006,3000,1006
 9988 CONTINUE
      READ(5,6040) IYEAR,LIM,IMON
 6040 FORMAT(3I3)
      IF(IYEAR.NE.1.OR.NA.LT.LIM) GO TO 6010
      TOT=0.0
      ADD= 0.0
      READ(5,6014) NV,NK,NOZ,(DES(JM),JM=1,10)
 6014 FORMAT(3I3,31X,10A4)
      WRITE(6,6016) NV,NK,NOZ,(DES(JM),JM=1,10)
 6016 FORMAT(1H1,3I3,31X,10A4)
      NOBS=NA
      NK=1
      DO 6012 JA=1,NA
      AZ(JA,1)=QANAV(JA)
      AZ(JA,2)=TDSAWA(JA)
      AZ(JA,3) = JA
      TOT = TOT+QANAV(JA)
 6012 ADD = ADD+TDSAWA(JA)
      CON(1) = TOT/NA
      CON(2) = CON(1)*CON(1)
      CON(3) = CON(2)*CON(1)
      CON(4)=NA/2
      CON(5) = CON(1)*CON(4)
      CON(6) = CON(2)*CON(4)
      CON(7) = CON(1)*CON(4)*CON(4)
      CON(8) = CON(4)*CON(4)
      CON(9) = ADD/NA
      CALL MDC(NV,NK,NOZ,NOBS,CON)
      READ(5,6040) NR
      DO 6030 JA=1,NR
      CALL SMR(NV,NR,NOZ,NOBS)
 6030 CONTINUE
 6010 IF(IMON.NE.1) GO TO 9999
      READ (5,6014) NV,NK,NOZ,(DES(JM),JM=1,10)
      WRITE(6,6016) NV,NK,NOZ,(DES(JM),JM=1,10)
      NOBS=NT
      NK=1
      TOT = 0.0
      ADD=0.0
      ALL = 0.0
      DO 6050 JA=1,NT
      AZ(JA,1) = QAVE(JA)
      AZ(JA,2) = TDSQTA(JA)
      AZ(JA,3) = TIME(JA)
      TOT = TOT+QAVE(JA)
      ADD = ADD+TDSQTA(JA)
 6050 ALL = ALL+TIME(JA)
      CON(1) = TOT/NT
      CON(2) = CON(1)*CON(1)
      CON(3) = CON(2)*CON(1)
      CON(4) = ALL/NT
      CON(5) = CON(1)*CON(4)
      CON(6) = CON(2)*CON(4)
      CON(7) = CON(1)*CON(4)*CON(4)
      CON(8) = CON(4)*CON(4)
      CON(9) = ADD/NT
      CALL MDC(NV,NK,NOZ,NOBS,CON)
      READ(5,6040) NR
      DO 6080 JA=1,NR
      CALL SMR(NV,NK,NOZ,NOBS)
 6080 CONTINUE
 9999 CONTINUE
      WRITE(6,5934)
 5934 FORMAT(1H1)
 9997 CONTINUE
      STOP
      END


WI FOR SUB1
      SUBROUTINE AADAY(KKK,I,WDAY)
      DIMENSION WDAY(3),AZ(300,3),ZP(50),AT(21,20)
      DOUBLE PRECISION ZP,AT
      COMMON AZ,ZP,AT
      GO TO(10,15,20,25,30,35,40,45,50,55,60,65),KKK
   10 WDAY(2)=31.
      WDAY(1) = 31.
```

Preceding page blank

```
      WDAY(3) = 29.
      GO TO 99
   15 WDAY(2) = 29.
      WDAY(1) = 31.
      WDAY(3) = 31.
      GO TO 99
   20 WDAY(2) = 31.
      WDAY(1) = 29.
      WDAY(3) = 30.
      GO TO 99
   25 WDAY(2) = 30.
      WDAY(1) = 31.
      WDAY(3) = 31.
      GO TO 99
   30 WDAY(2) = 31.
      WDAY(1) = 30.
      WDAY(3) = 30.
      GO TO 99
   35 WDAY(2) = 30.
      WDAY(1) = 31.
      WDAY(3) = 31.
      GO TO 99
   40 WDAY(2) = 31.
      WDAY(1) = 30.
      WDAY(3) = 31.
      GO TO 99
   45 WDAY(2) = 31.
      WDAY(1) = 31.
      WDAY(3) = 30.
      GO TO 99
   50 WDAY(2) = 30.
      WDAY(1) = 31.
      WDAY(3) = 31.
      GO TO 99
   55 WDAY(2) = 31.
      WDAY(1) = 30.
      WDAY(3) = 30.
      GO TO 99
   60 WDAY(2) = 30.
      WDAY(1) = 31.
      WDAY(3) = 31.
      GO TO 99
   65 WDAY(2) = 31.
      WDAY(1) = 30.
      WDAY(3) = 31.
   99 RETURN
      END


WI FOR SUB2
      SUBROUTINE MDC(NV.NK.NOZ.NOBS.CON)
C     MULTIVARIATE DATA COLLECTION
C   ANALOG COMPUTER PROGRAM
C     UTAH STATE UNIVERSITY
      INTEGER FMT.DES
      DIMENSION FMT(60).IJ(50.4).X(50).CON(50).IX(50).AZ(300.3).
     1C(50.2).DES(10).AT(21.20).SUM(50).G(50).ZP(50).AP(20)
      DOUBLE PRECISION X.CON.C.ZC.AT.SD.OBS.CNT.SUM.G.ZP.AP
      COMMON AZ.ZP.AT
      CNT=0.0
      DO 1 J=1.NV
      SUM(J)=0.0
      G(J)=0.0
      DO 1 I=1.NPL
    1 AT(I.J) = 0.0
      WRITE (6.113)NOBS
  113 FORMAT( //1H .I5.5X15HGROUP SIZE CARD)
      OBS=NOBS
      CNT=CNT*OBS
      NPL=NV*1
      WRITE (6.1020)
 1020 FORMAT(/33H    VARIABLE SPECIFICATION CARDS /17H  V TRN  ORIG VA
     15X.8HCONSTANT 7X.2HC15X2HC210X11HDESCRIPTION )
      DO 4 I=1.NV
      READ(5.102) IX(I).(IJ(I.J).J=1.4).CC1.CC2.
     1(DES(J).J=1.8)
  102 FORMAT(5I3.15X.2F7.2.4X.8A4)
      C(I.1) = CC1
      C(I.2) = CC2
    4 WRITE(6.112) I.IX(I).(IJ(I.J).J=1.4).CON(I).C(I.1).C(I.2).
     1(DES(J).J=1.8)
  112 FORMAT(1H .6I3.E15.7.2F7.2.4X.8A4)
C     READ DATA CARDS AND MAKE TRANSFORMATIONS
      DO 40 K=1.NOBS
      DO 30 I=1.NV
C     ADDITIONAL TRANSFORMATIONS SHOULD BE ADDED BELOW
      ID=IX(I)
      GO TO (21.22.23.24).ID
   21 N1 = IJ(I.1)
      X(I) = AZ(K.N1)-CON(I)
      GO TO 30
   22 N1 = IJ(I.1)
      N2 = IJ(I.2)
      X(I) = AZ(K.N1)*AZ(K.N2)-CON(I)
      GO TO 30
   23 N1 = IJ(I.1)
      N2 = IJ(I.2)
      N3 = IJ(I.3)
      X(I) = AZ(K.N1)*AZ(K.N2)*AZ(K.N3)-CON(I)
      GO TO 30
   24 N1 = IJ(I.1)
      N2 = IJ(I.2)
      N3 = IJ(I.3)
      N4 = IJ(I.4)
      X(I) = AZ(K.N1)*AZ(K.N2)*AZ(K.N3)*AZ(K.N4)-CON(I)
   30 CONTINUE
      DO 45 I=1.NV
      SUM(I)=SUM(I)*X(I)
      DO 45 J = I.NV
   45 AT(I.J) = AT(I.J)*X(I)*X(J)
   40 CONTINUE
C     PUNCH WITHIN GROUP MEANS AND STANDARD DEVIATIONS
      WRITE  (6.1041)
 1041 FORMAT( //2X42HWITHIN GROUP MEANS AND STANDARD DEVIATIONS)
      WRITE (6.1040)
 1040 FORMAT(//        2X3HGRP.2X3HVAR.23X4HMEAN.11X6HST DEV)
      DO 8 I=1.NV
      X(I)=SUM(I)/OBS
      ZP(I) = X(I)*CON(I)
      G(I)=G(I)*SUM(I)
      DO 9 J=1.I
      AT(J.I) = AT(J.I)-SUM(I)*X(J)
    9 AT(I*1.J) = AT(I*1.J)*AT(J.I)
C     FOR SINGLE PRECISION THE D IN DSQRT SHOULD BE OMITTED IN THE
C     FOLLOWING STATEMENT
      SD = DSQRT(AT(I.I)/(OBS-1.))
    8 WRITE(6.104) L.I.SUM(I).ZP(I).SD
  104 FORMAT(1H 2I5.3E16.7)
C     PUNCH SUMS OF SQUARES AND PRODUCTS
      WRITE (6.1050)
 1050 FORMAT(//         2X3HGRP.2X3HVAR.11X.
     139HSS AND SP MATRIX BY COLUMNS WITHIN ROWS)
      DO 12 I=1.NV
   12 WRITE(6.105) L.I.(AT(I.J).J=I.NV)
  105 FORMAT (1H 2I5.4(2X.E14.7)/(11X.4(2X.E14.7)))
C     PUNCH CORRELATIONS
      WRITE (6.1060)
 1060 FORMAT(//         2X3HGRP.2X3HVAR.9X.
     141HCORRELATION MATRIX BY COLUMNS WITHIN ROWS)
      DO 15 I=1.NV
C     FOR SINGLE PRECISION THE D IN DSQRT SHOULD BE OMITTED IN THE
C     FOLLOWING STATEMENT
   15 X(I) = DSQRT(AT(I.I))
      DO 16 I=1.NV
      DO 50 J=I.NV
   50 AP(J) = AT(I.J)/(X(I)*X(J))
   16 WRITE(6.105) L.I.(AP(J).J=I.NV)
      CONTINUE
      RETURN
      END


WI FOR SUB3
      SUBROUTINE SMR(NOV.IH.IYZ.NOBS)
C     STEPWISE MULTIPLE REGRESSION
C   ANALOG COMPUTER PROGRAM
C     UTAH STATE UNIVERSITY
C     THIS PROGRAM USES THE OUTPUT OF MULTIVARIATE DATA COLLECTION
C     NJB= NUMBER OF JOBS
C     NX= NUMBER OF INDEPENDENT VARIABLES DESIRED
C     NY= NUMBER OF DEPENDENT VARIABLES DESIRED
C     IX=1 PUNCH ORIGINAL INVERSE
C     IY=1 STEPWISE
C     IZ=1 PUNCH SUCCESSIVE INVERSES
C     IDY= DEPENDENT VARIABLE TO CONTROL ON FOR STEPWISE SOLUTION
C     IF ONLY ONE DEPENDENT VARIABLE IDY=1
      INTEGER FMT
      DIMENSION A(21.20).X(50).REG(50).BZERO(50).RES(50).ID(50).RS
     1AVE(50).FMT(60).Z(50).IZ(5).AT(21.20).ZP(50).AZ(300.3)
      DOUBLE PRECISION A.AERR.STAN.ATOT.SMALL.AVOD.AY.TOTMS.RMOD.R
     1ELEM.DET.X.AVE.REG.BZERO.Z.RES.RSQ.X1.X2.X3.R.REC.AT.ZP
      COMMON AZ.ZP.AT
      READ  (5.100) JOB.NX.NY.IX.IY.IZZ.IDY.(FMT(I).I=1.10)
      WRITE (6.101) JOB.NX.NY.IX.IY.IZZ.IDY.(FMT(I).I=1.10)
  101 FORMAT( 1H1.I5.2I3.3I2.I3.20X.10A4)
  100 FORMAT(     I5.2I3.3I2.I3.20X.10A4)
C     READ SELECTION VECTOR
      NV=NX*NY
      READ   (5.102) (ID(I).I=1.NV)
  102 FORMAT(20I4)
      WRITE  (6.2020)
 2020 FORMAT(18H  SELECTION VECTOR //)
      WRITE(6.202)   (ID(I).I=1.NV)
  202 FORMAT(1H .20I4)
  110 FORMAT(2H  )
      DO 60 I=1.NOV
      DO 61 J=1.NV
      IF(I-ID(J)) 61.62.61
   61 CONTINUE
      GO TO 60
   62 AVE(J) = ZP(I)
   60 CONTINUE
C     SELECT DESIRED SS AND SP MATRIX
      DO 50 I=1.NOV
      DO 58 J=I.NOV
   58 Z(J) = AT(I.J)
      DO 50 J=I.NOV
      DO 51 K=1.NV
      IF(I-ID(K)) 51.52.51
   51 CONTINUE
      GO TO 50
   52 DO 53 L=1.NV
      IF(J-ID(L)) 53.54.53
   53 CONTINUE
      GO TO 50
   54 IF(K-L) 55.56.55
   56 A(K.L)=Z(J)
C     FOR SINGLE PRECISION THE D IN DSQRT SHOULD BE OMITTED IN THE
C     FOLLOWING STATEMENT
      X(K)=DSQRT(A(K.L))
      GO TO 50
   55 A(L.K)=Z(J)
      A(K.L)=Z(J)
   50 CONTINUE
C     COMPUTE INVERSE AND SOLUTIONS
      NK=NX
      NXPO=NX*1
      DET=1.0
      DO 501 L=1.NK
      DET=DET*A(L.L)
      REC=1./A(L.L)
      DO 502 I=1.NK
      IF(I-L) 503.504.505
  503 R=A(I.L)*REC
      GO TO 506
  504 R=0.0
      GO TO 506
  505 R=A(L.I)*REC
  506 DO 508 J=I.NK
      IF(J-L) 507.508.509
  507 A(I.J)=A(I.J)-R*A(J.L)
      GO TO 508
  509 A(I.J)=A(I.J)-R*A(L.J)
  508 CONTINUE
      DO 510 J=NXPO.NV
  510 A(I.J)=A(I.J)-R*A(L.J)
```

```
      IF(I-L) 511,512,513
  511 A(I,L)=R
      GO TO 502
  512 A(L,L)=-REC
      GO TO 502
  513 A(L,I)=R
  502 CONTINUE
      DO 501 N=NXPO,NV
  501 A(L,N)=A(L,N)*REC
C     CHANGE SIGN OF INVERSE AND BRING IT TO A SQUARE
      IF(IX-1) 520,521,520
  521 WRITE (6,129)
  129 FORMAT (/15H INVERSE MATRIX )
  520 DO 10 I=1,NX
      DO 80 J=I,NX
      A(I,J)=-A(I,J)
   80 A(J,I)=A(I,J)
C     PUNCH OUT INVERSE ON INTERNAL SWITCH OPTION
      IF(IX-1) 10,11,10
   11 WRITE(6,112) ID(I),(A(I,J),J=1,NX)
  112 FORMAT(1H ,I5,4(2X,E16.7)/(6X,4(2X,E16.7)))
   10 CONTINUE
      NTOT=NOBS-1
      ATOT=NTOT
      AY=NY
      NB=1
   72 DO 12 J=NXPO,NV
      REG(J)=0.0
      BZERO(J)=AVE(J)
      DO 13 I=1,NX
      REG(J)=REG(J)+A(J,I)*A(I,J)
   13 BZERO(J)=BZERO(J)-A(I,J)*AVE(I)
      RES(J)=A(J,J)-REG(J)
   12 RSQ(J)=REG(J)/A(J,J)
      NERR=NTOT-NX
      AERR=NERR
      SMALL=.99999999E+35
C     PUNCH OUT THE ANALYSIS FOR EACH DEPENDENT VARIABLE
      DO 14 J=NXPO,NV
      WRITE(6,103) JOB,ID(J)
  103 FORMAT(/29H  REGRESSION ANALYSIS OF JOB I5,10H, VARIABLEI5/)
      WRITE(6,104)
  104 FORMAT(7H SOURCE3X2HDF3X11HMEAN SQUARE3X3HVAR4X11HCOEFFICIENT,
     14X7HST COEF6X4HMEAN)
      TOTMS=A(J,J)/ATOT
      WRITE(6,105) NTOT,TOTMS,BZERO(J),AVE(J)
  105 FORMAT(7H  TOTAL,I5,E16.7,4H   0,E16.7,13X,E16.7)
      DO 15 I=1,NX
      BMS=A(I,J)*A(I,J)/A(I,I)
      IF (J-IDY-NX) 16,30,16
   30 IF(SMALL-BMS) 16,16,17
C     DETERMINE VARIABLE TO BE DELETED
   17 SMALL=BMS
      KZ=I
   16 STAN=A(I,J)*X(I)/X(J)
   15 WRITE(6,106) ID(I),NB,BMS,ID(I),A(I,J),STAN,AVE(I)
  106 FORMAT(4H  V,I3,I5,E16.7,I4,E16.7,E13.4,E16.7)
      AMOD=NX
      BMOD=REG(J)/AMOD
      WRITE(6,107) NX,BMOD,RSQ(J)
  107 FORMAT(7H  MODEL,I5,E16.7,7X7HR SQR  ,F15.7)
      RES(J)=RES(J)/AERR
   14 WRITE(6,108) NERR,RES(J),DET
  108 FORMAT(7H  ERROR,I5,E16.7,7X7HDET=   ,E15.7)
      IF(IY-1) 20,21,20
   21 WRITE(6,192) ID(KZ)
  192 FORMAT(/10H VARIABLE I5,17H HAS BEEN DELETED/)
      IZZ=NX*IY
      IF(NX-1) 22,20,22
   22 IF(KZ-NX) 24,25,25
C     REORDER MATRIX, IDENTIFICATIONS, MEANS, ETC.
   24 DO 26 I=1,NV
      ELEM=A(I,NX)
      A(I,NX)=A(I,KZ)
   26 A(I,KZ)=ELEM
      DO 27 I=1,NV
      ELEM=A(NX,I)
      A(NX,I)=A(KZ,I)
   27 A(KZ,I)=ELEM
      ELEM=X(NX)
      X(NX)=X(KZ)
      X(KZ)=ELEM
      IEL=ID(NX)
      ID(NX)=ID(KZ)
      ID(KZ)=IEL
      ELEM=AVE(NX)
      AVE(NX)=AVE(KZ)
      AVE(KZ)=ELEM
C     DELETE VARIABLE FROM MODEL
C     REDUCE ORDER OF INVERSE AND SOLUTION
   25 NL=NX
      DET=DET*A(NX,NX)
      NX=NX-1
      DO 70 I=1,NX
      DO 71 J=1,NX
   71 A(I,J)=A(I,J)-A(I,NL)/A(NL,NL)*A(NL,J)
      DO 70 J=NXPO,NV
   70 A(I,J)=A(I,J)-A(I,NL)/A(NL,NL)*A(NL,J)
      IF(IZZ-1) 72,73,72
   73 WRITE(6,110)
      DO 74 I=1,NX
   74 WRITE(6,112) JOB,ID(I),(A(I,J),J=1,NX)
      GO TO 72
   20 CONTINUE
C     BYPASS CORRELATION MATRIX
   91 CONTINUE
      RETURN
      END
 @ XQT GTDS
```

Sample Output of Computer Program

```
BLACKS FORK RIVER NEAR MILLBURNE, WYOMING   MONTHLY AVERAGES                      ANNUAL AVERAGES
  DATE          Q         TDS       QAVE       ATDST      ATDSQT        QANAV      TDSAAT       TDSAQT
 6 23 59     658.00      39.00     882.00      44.97      45.13

 7  2 59     426.00      35.00
 7 15 59     244.00      34.00     267.82      37.63      35.90

 8  3 59     117.00      50.00
 8 24 59      60.00      74.00      84.82      63.55      59.58

 8 14 59      39.00      66.00      43.78      67.67      68.52

 8 12 59      74.00      77.00      74.00      77.00      77.00

 8 18 59      32.00      86.00      32.00      86.00      86.00       230.59      71.98       60.16

 8 22 60     220.00      79.00     220.00      79.00      79.00

 5 12 60     716.00      59.00
 5 20 60     296.00      71.00     595.55      61.71      55.90

 6  3 60    1180.00      37.00
 6 17 60     640.00      24.00     763.40      31.73      32.05

 7  1 60     257.00      41.00
 7 15 60     133.00      49.00     165.00      46.94      45.78

 7 19 60      43.80      93.00      47.35      90.87      87.02

 7 14 60      35.00     101.00      38.97     100.33     100.14

 7 13 60      49.00      93.00      46.55      95.71      94.75

 7 10 60      30.00     114.00      29.27     116.75     116.94

 7  9 60      26.00     129.00      26.86     130.26     130.41       211.56      83.79       56.00

 7  4 61      30.00     135.00      28.31     135.97     135.79

 7  7 61      23.00     139.00      23.00     139.00     139.00

 7  4 61      66.00      63.00      66.00      63.00      63.00

 7  5 61     109.00      48.00     109.00      48.00      48.00        57.13      93.76       68.31

 5 20 63     450.00      66.00
 5 31 63     492.00      50.00     457.85      63.16      62.95

 5 21 63     555.00      58.00     515.28      58.07      58.06

 7  5 63     290.00      51.00
 7 26 63     101.00      61.00     195.50      56.00      53.58

 8  9 63      86.00      83.00
 8 21 63      67.50      76.00      74.90      77.97      77.83

10  1 63      49.00      50.00
10 15 63      51.00      59.00
10 30 63      36.50      78.00      47.34      61.89      60.83
12  2 63      25.00      94.00
12 18 63      25.00     114.00      24.68     107.35     107.31       190.83      71.60       60.10

12  9 64      20.00     111.00      20.00     111.00     111.00

12 17 64      43.70     116.00      43.70     116.00     116.00

12 27 64     900.00      33.00     706.60      51.76      34.16

 6  8 64     775.00      39.00
 6 30 64     700.00      21.00     755.83      32.00      32.41

 7  7 64     450.00      28.00
 7 23 64     200.00      36.00     344.16      31.87      28.82

 8  5 64      96.00      47.00
 8 25 64      43.00      67.00      68.47      57.65      53.40

 9  5 64      32.00      75.30
 9 17 64      42.00      73.00      38.33      73.73      73.61

11  5 64      34.00     129.00
11 10 64      44.00     107.00
11 19 64      30.00     126.00      34.87     122.09     120.94

12  2 64      34.00     137.00
12 17 64      32.00     131.00
12 30 64      30.00     141.00      32.13     133.79     133.58       227.26      80.90       48.70

 1 14 65      36.00     129.00
 1 28 65      36.00     127.00      34.74     130.87     130.50

 2 11 65      36.00     142.00
 2 26 65      34.00     134.00      35.20     137.03     137.10

 3 11 65      22.00     144.00
 3 25 65      24.00     144.00      24.30     142.71     142.20

 4  8 65      26.00     130.00
 4 22 65      66.00     109.03
 4 27 65      76.00     110.00      44.77     120.15     115.60

 5  6 65     170.00     106.00
 5 20 65     296.00      84.00     248.45      92.77      88.65

 6  3 65     520.00      79.00
 6 16 65    1400.00      56.00
 6 28 65     600.00      59.00     910.67      62.27      59.52

 6 12 65     700.00      42.00     593.55      43.19      43.66

 9  2 65     175.00      61.00
 9 13 65      96.06      69.00
 9 15 65     167.00      62.00
 9 30 65     100.00      61.00     129.90      61.93      61.77

10 13 65      90.00      74.00
10 16 65      85.00      69.00
10 25 65      81.00      87.00      89.15      79.13      76.40

11  6 65      60.00     101.00
11 10 65      57.00     102.00
11 23 65      39.00     110.00      50.09     104.83     103.60

11  8 65      69.00     117.00      68.82     116.40     116.91       219.61      96.81       65.54
```

Regression Analysis for the Development of Monthly Mathematical Models Relating Total Salinity to Water Flow Rate and Time for Blacks Fork near Millburne, Wyoming

```
  49     GROUP SIZE CARD

  VARIABLE SPECIFICATION CARDS
V TR.  ORIG VAR     CONSTANT        C1     C2     DESCRIPTION OF VARIABLES
1  1   1 -0 -0 -0   .2027785+03     .00    .00    X(1)           FLOW
2  2   1  1 -0 -0   .4111913+05     .00    .00    X(1)X(1)       FLOW SQUARED
3  3   1  1  1 -0   .8338077+07     .00    .00    X(1)X(1)X(1)   FLOW CUBED
4  1   3 -0 -0 -0   .7224490+01     .00    .00    X(3)           TIME
5  2   1  3 -0 -0   .1464971+04     .00    .00    X(1)X(3)       FLOW-TIME
6  3   1  1  3 -0   .2970644+06     .00    .00    X(1)X(1)X(3)   FLOW SQUARED
                                                                   TIME
7  3   1  3  3 -0   .1058367+05     .00    .00    X(1)X(3)X(3)   FLOW-TIME
                                                                  SQUARED
8  2   3  3 -0 -0   .5219325+02     .00    .00    X(3)X(3)       TIME SQUARED
9  1   2 -0 -0 -0   .8181697+02     .00    .00    Y              TDS

 WITHIN GROUP MEANS AND STANDARD DEVIATIONS

GRP  VAR                             MEAN           ST DEV
  0    1      .1139164-02      .2027786+03     .0000000
  0    2      .3156544+07      .1055384+06     .0000000
  0    3      .3105240+10      .7171134+08     .4635424+01
  0    4      .2775550-16      .7224490+01     .0000000
  0    5     -.9340436+04      .1274350+04     .0000000
  0    6      .1609976+08      .6256313+06     .2792023+01
  0    7     -.9812828+05      .8581053+04     .1633877+01
  0    8      .4885306+03      .6216327+02     .8375575-00
  0    9      .4341662-03      .8181698+02     .8160821-00

GRP  VAR            SS AND SP MATRIX BY COLUMNS WITHIN ROWS
  0    1      .3156544+07      .2465210+10      .1903021+13     -.9340444+04
              .1799380+08      .1444066+11      .1001726+09     -.1971919+06
             -.2659222+06
  0    2      .2069776+13      .1673011+16     -.6704660+07      .1406608+11
              .1215536+14      .7830082+11     -.1360348+09     -.1765291+09
  0    3      .1396524+19     -.4728784+10      .1091286+14      .9859425+16
              .6103704+14     -.9575601+11     -.1246538+12
  0    4      .4885306+03     -.3068839+05     -.3603832+08      .2797842+04
              .6668204+04     -.6284088+03
  0    5      .1058607+09      .8361032+11      .6119054+09     -.8411803+06
             -.1058868+07
  0    6      .7201031+14      .4731160+12     -.7579396+09     -.1056588+10

  0    7      .3694976+10     -.2410681+07     -.1017026+08
  0    8      .9646469+05      .4971900+04
  0    9      .5494754+05

GRP  VAR          CORRELATION MATRIX BY COLUMNS WITHIN ROWS
  0    1      .3376512+07      .8968182+09      .2606801+12     -.1358061+05
              .1123129+08      .4294967+10      .6710886+08     -.2621440+06
             -.5242880+06
  0    2      .2560754+12      .7793983+14     -.3315298+07      .2986060+10
              .2199023+13      .3435974+11     -.1191297+09     -.1342177+09
  0    3      .2449745+17     -.8804591+09      .8722748+12      .1125900+16
              .8796093+13     -.3157548+11     -.3435974+11
  0    4      .9654701+03     -.2600218+05     -.3355443+08      .4096000+04
              .1638400+05     -.2048000+04
  0    5      .3855601+08      .3435974+11      .5368709+09     -.1048576+07
             -.2097152+07
  0    6      .8796093+13      .6871948+11     -.2684355+09     -.2684355+09

  0    7      .1073742+10     -.2097152+07     -.8388608+07
  0    8      .1310720+06      .8192000+04
  0    9      .6553600+05
```

MONTHLY MODEL FOR TDS VERSUS FLOW

```
  1   2   3   9 (VARIABLES)

INVERSE MATRIX
   1      .2583165-04    -.7308457-07     .5235365-10
   2      .2220339-09    -.1664015-12
   3      .1287206-15

 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1208140+03                  .8181698+02
 V. 1     1    .9437007+04   1    -.4937342-00    -.5000-00     .2027786+03
 V. 2     1    .4342545+04   2     .9819385-03     .3906-02     .1055384+06
 V. 3     1    .2730048+04   3    -.5928013-06    -.7629-05     .7171134+08
 MODEL    3    .1061636+05       R SQR=      .5796265-00
 ERROR   45    .5133002+03       DET=        .3543161+34

VARIABLE   3 HAS BEEN DELETED

 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1102900+03                  .8181698+02
 V. 1     1    .1406304+05   1    -.2526282-00    -.5000-00     .2027786+03
 V. 2     1    .6716477+04   2     .2156042-03     .9766-03     .1055384+06
 MODEL    2    .1455951+05       R SQR=      .5299419-00
 ERROR   46    .5614904+03       DET=        .4560777+10

VARIABLE   2 HAS BEEN DELETED

 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .9890000+02                  .8181698+02
 V. 1     1    .2240255+05   1    -.8424474-01    -.1250+00     .2027786+03
 MODEL    1    .2240255+05       R SQR=      .4077077-00
 ERROR   47    .6924475+03       DET=        .3156544+07

VARIABLE   1 HAS BEEN DELETED
```

MONTHLY MODEL FOR TDS VERSUS [illegible]

```
  1   2   3   4   5   6   7   8   9 (VARIABLES)

INVERSE MATRIX
   1      .8433224-03    -.4821874-06    -.1262403-10     [illegible]
         -.2444792-03     .8944005-07     .1624839-04    -.5276615-03
   2      .7678165-09    -.2015224-12    -.1401212-05     .8503248-07
         -.8267767-10    -.3509238-08     .5942812-08
   3      .1805470-15    -.2288561-08     .3157930-10    -.7706716-14
         -.2493445-11     .1799333-09
   4      .1636132-00    -.2703253-02     .8777425-06     .1847763-07
         -.1176625-01
   5      .7785395-04    -.2386184-07    -.5420244-05     .1984287-03

   6      .1590788-10     .1326857-08    -.5148808-07
   7      .3937847-06    -.1398078-04
   8      .8823562-03

 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1380179+03                  .8181698+02
 V. 1     1    .6615707+03   1     .7469387-00     .1000+01     .2027786+03
 V. 2     1    .8160770+03   2    -.7915791-03    -.3906-02     .1055384+06
 V. 3     1    .8704153+02   3    -.1253598-06    -.9537-06     .7171134+08
 V. 4     1    .1006535+04   4    -.1283287+02    -.1600+02     .7224490+01
 V. 5     1    .5886808+03   5    -.2140821-00    -.5000-00     .1274350+04
 V. 6     1    .2098877+04   6     .1832419-03     .4049-03     .6256313+06
 V. 7     1    .1835582+03   7     .8501907-02     .1722-01     .8581053+04
 V. 8     1    .1156554+04   8     .1010194+01     .1772+01     .6216327+02
 MODEL    8    .5609855+04       R SQR=      .8167572-00
 ERROR   40    .2517187+03       DET=   ***************

*VARIABLE   3 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1395485+03                  .8181698+02
 V. 1     1    .6468108+03   1     .7381728-00     .1000+01     .2027786+03
 V. 2     1    .1598318+04   2    -.9315029-03    -.3906-02     .1055384+06
 V. 8     1    .1832791+04   8     .1135128+01     .1992+01     .6216327+02
 V. 4     1    .1545205+04   4    -.1442189+02    -.1600+02     .7224490+01
 V. 5     1    .5104867+03   5    -.1921558-00    -.5000-00     .1274350+04
 V. 6     1    .2019614+04   6     .1778908-03     .3931-03     .6256313+06
 V. 7     1    .1275678+03   7     .6770624-02     .1372-01     .8581053+04
 MODEL    7    .6398828+04       R SQR=      .8151731-00
 ERROR   41    .2477022+03       DET=   ***************

*VARIABLE   7 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9
SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1486481+03                  .8181698+02
 V. 1     1    .1535260+04   1     .4353160-00     .5000-00     .2027786+03
 V. 2     1    .1527344+04   2    -.8129461-03    -.3906-02     .1055384+06
 V. 8     1    .5449717+04   8     .1351725+01     .2000+01     .6216327+02
 V. 4     1    .4321650+04   4    -.1730783+02    -.1600+02     .7224490+01
 V. 5     1    .3015098+04   5    -.9824790-01    -.2500-00     .1274350+04
 V. 6     1    .2081975+04   6     .1548964-03     .3423-03     .6256313+06
 MODEL    6    .7444038+04       R SQR=      .8128515-00
 ERROR   42    .2448419+03       DET=   ***************

*VARIABLE   2 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1623304+03                  .8181698+02
 V. 1     1    .5996248+02   1     .3172578-01     .6250-01     .2027786+03
 V. 6     1    .2421257+04   6     .2355192-04     .5204-04     .6256313+06
 V. 8     1    .5534252+04   8     .1362027+01     .2000+01     .6216327+02
 V. 4     1    .5919265+04   4    -.1970058+02    -.1600+02     .7224490+01
 V. 5     1    .2191574+04   5    -.3454540-01    -.6250-01     .1274350+04
 MODEL    5    .8627377+04       R SQR=      .7850551-00
 ERROR   43    .2746675+03       DET=        .5130534+32

*VARIABLE   1 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1640079+03                  .8181698+02
 V. 5     1    .5110769+04   5    -.2083268-01    -.6250-01     .1274350+04
 V. 6     1    .2687640+04   6     .2430127-04     .5369-04     .6256313+06
 V. 8     1    .5509064+04   8     .1358508+01     .2000+01     .6216327+02
 V. 4     1    .6111681+04   4    -.1990810+02    -.1600+02     .7224490+01
 MODEL    4    .1076923+05       R SQR=      .7839639-00
 ERROR   44    .2697878+03       DET=        .8612070+27
*VARIABLE   6 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1717572+03                  .8181698+02
 V. 5     1    .5876772+04   5    -.9090663-02    -.1562-01     .1274350+04
 V. 4     1    .1364364+05   4    -.2617740+02    -.3200+02     .7224490+01
 V. 8     1    .1183174+05   8     .1781408+01     .2000+01     .6216327+02
 MODEL    3    .1346309+05       R SQR=      .7350511-00
 ERROR   45    .3235179+03       DET=        .1892319+15
*
 VARIABLE   5 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9
SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .1817734+03                  .8181698+02
 V. 8     1    .3370417+05   8     .2497508+01     .4000+01     .6216327+02
 V. 4     1    .3425625+05   4    -.3523959+02    -.3200+02     .7224900+01
 MODEL    2    .1725625+05       R SQR=      .6240987-00
 ERROR   46    .4442408+03       DET=        .2561010+07
*VARIABLE   8 HAS BEEN DELETED
 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT     ST COEF        MEAN
 TOTAL   48    .1144741+04   0     .9111601+02                  .8181698+02
 V. 4     1    .8083375+03   4    -.1286324+01    -.1000+01     .7224490+01
 MODEL    1    .8083375+03       R SQR=      .1471106-01
 ERROR   47    .1151899+04       DET=        .4885306+03
*
 VARIABLE   4 HAS BEEN DELETED
```

Regression Analysis for the Development of Yearly Mathematical Models Relating Total Salinity to Water Flow Rate for Blacks Fork near Marston, Wyoming

```
 9  1  3 (VARIABLES)

   9     GROUP SIZE CARD

  VARIABLE SPECIFICATION CARDS
V TRN  ORIG VAR      CONSTANT        C1      C2     DESCRIPTION OF VARIABLES
 1  1  1  0  0  0    .1850227+03    .00     .00     X(1)           FLOW
 2  2  1  1 -0 -0    .3423340+05    .00     .00     X(1)X(1)       FLOW SQUARED
 3  3  1  1  1 -0    .6333957+07    .00     .00     X(1)X(1)X(1)   FLOW CUBED
 4  1  3 -0 -0 -0    .4500000+01    .00     .00     X(3)           TIME
 5  2  1  3 -0 -0    .8326022+03    .00     .00     X(1)X(3)       FLOW-TIME
 6  3  1  1  3 -0    .1540503+06    .00     .00     X(1)X(1)X(3)   FLOW SQUARED-TIME
 7  3  1  3  3 -0    .3746710+04    .00     .00     X(1)X(3)X(3)   FLOW-TIME SQUARED
 8  2  3  3 -0 -0    .2025000+02    .00     .00     X(3)X(3)       TIME SQUARED
 9  1  2 -0 -0 -0    .9333354+03    .00     .00     Y              TDS

 WITHIN GROUP MEANS AND STANDARD DEVIATIONS


GRP  VAR                        MEAN          ST DEV
  0    1    .3385544-04    .1850227+03    .0000000
  0    2    .1676924+06    .5286589+05    .0000000
  0    3    .9512810+08    .1690375+08    .0000000
  0    4    .4500000+01    .5000000+01    .0000000
  0    5    .1464625+04    .9953382+03    .0000000
  0    6    .1241278+07    .2919701+06    .0000000
  0    7    .2749266+05    .6801450+04    .1658232+01
  0    8    .1027500+03    .3166667+02    .7346884-00
  0    9    .6866455-04    .9333354+03    .0000000

GRP  VAR         SS AND SP MATRIX BY COLUMNS WITHIN ROWS
  0    1    .1676924+06    .6410121+08    .2350629+11    .6320222+03
            .9702889+06    .3882897+09    .7438207+07    .8481575+04
           -.4547407+06
  0    2    .2650127+11    .1021363+14    .2487655+06    .4009045+09
            .1720647+12    .3280229+10    .3697233+07   -.1507173+09
  0    3    .4067110+16    .1138109+09    .1595575+12    .7064493+14
            .1368970+13    .1698744+10   -.5030326+11
  0    4    .6000000+02    .1642283+05    .5625359+07    .1662943+06
            .6000000+03   -.2404514+04
  0    5    .9847727+07    .3900831+10    .9008953+08    .1886881+06
           -.2307640+07
  0    6    .1636481+13    .3624102+11    .6780576+08   -.7775211+09

  0    7    .8602824+09    .1919003+07   -.1554496+08
  0    8    .6308000+04   -.2516696+05
  0    9    .1620722+07


GRP  VAR        CORRELATION MATRIX BY COLUMNS WITHIN ROWS
  0    1    .2621440+06    .3355443+08    .8589934+10    .2048000+04
            .1048576+07    .2684355+09    .8375373+07    .1978869+05
           -.5242880+06
  0    2    .8589934+10    .2199023+13    .2621440+06    .2567419+09
            .4680819+11    .1268146+10    .2961736+07   -.1270232+09
  0    3    .2814750+15    .6710886+08    .4538825+11    .8536536+13
            .2350874+12    .6044606+09   -.1717987+11
  0    4    .2438564+03    .2778642+05    .4043051+07    .1698522+06
            .1269842+04   -.5353971+04
  0    5    .6936213+07    .1167127+10    .3830628+08    .1662435+06
           -.2139038+07
  0    6    .2079918+12    .6545916+10    .2537705+08   -.3061519+09

  0    7    .2208239+09    .1020670+07   -.8698598+07
  0    8    .6951935+04   -.2918065+05
  0    9    .1977074+07



   1    2    3    4    (VARIABLES)

INVERSE MATRIX
   1     .6020318-03    -.3582690-05     .5517612-08
   2     .2249424-07    -.3578269-10
   3     .5821641-13

 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT    ST COEF      MEAN
 TOTAL    8    .2025902+06   0      .1728181+04                 .9333354+03
 V, 1     1    .2139393+06   1    -.1134893+02   -.5640+01     .1850227+03
 V, 2     1    .6730375+05   2     .3890947-01    .5632-01     .5286589+05
 V, 3     1    .3399747+05   3    -.4448832-04   -.1450-03     .1690375+08
 MODEL    3    .5114663+06        R SQR=      .9467380-00
 ERROR    5    .1726456+05        DET=        .5756025+28

VARIABLE   3 HAS BEEN DELETED


 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT    ST COEF      MEAN
 TOTAL    8    .2025902+06   0      .1641617+04                 .9333354+03
 V, 1     1    .6432460+06   1    -.7132434+01   -.3545+01     .1850227+03
 V, 2     1    .2672557+06   2     .1156474-01    .1674-01     .5286589+05
 MODEL    2    .7502007+06        R SQR=      .9257613-00
 ERROR    6    .2005338+05        DET=        .3350951+15

VARIABLE   2 HAS BEEN DELETED


 REGRESSION ANALYSIS OF JOB  4268, VARIABLE  9

SOURCE   DF   MEAN SQUARE   VAR    COEFFICIENT    ST COEF      MEAN
 TOTAL    8    .2025902+06   0      .1435072+04                 .9333354+03
 V, 1     1    .1233146+07   1    -.2711756+01   -.1348+01     .1850227+03
 MODEL    1    .1233146+07        R SQR=      .7608621-00
 ERROR    7    .5536799+05        DET=        .1676924+06

VARIABLE   1 HAS BEEN DELETED
```

APPENDIX H

Subbasin Modeling Coefficients
Subbasin Observed and Computed Outflow Graphs

Table H-1. Single constant input parameters or coefficients for subbasin within the Green Division.

Subbasin	k_u	k_a	k_b	k_c	k_s	Efficiency (%)	M_{es} (inches)	M_{cs} (inches)	k_d (%)	C_q (P.P.M.)	C_s	C_{qs} (P.P.M.)
New Fork River Basin	0.03	0.02	0.31	-	5.0	55	2.0	4.5	7.3	210	1.0	120
Green River above LaBarge, Wyo.	0.32	0.66	0.50	-	3.0	50	2.0	6.0	1.2	650	1.25	320
Green River above Fontenelle Dam	-	-	-	-	2.0	40	2.0	5.0	-	-	1.25	540
Big Sandy Creek Basin	-	0.77	1.50	-	5.0	54	2.0	5.0	3.3	2,150	1.33	1,550
Green River above Green River, Wyoming	-	-	0.292	-	2.0	50	2.0	3.6	-	590	1.25	660
Blacks Fork River Basin	-	0.38	4.0	-	5.0	62	2.0	6.0	9.8	2,500	1.6	1,105
Green River above Flaming Gorge Dam	0.08	0.80	0.47	-	.05	60	2.0	5.0	-	-	1.25	1,500
Little Snake River Basin	0.28	0.565	5.9	-	2.0	60	2.0	6.5	3.8	820	1.5	700
Yampa River Basin	0.13	0.808	1.65	-	2.0	50	2.0	5.0	8.8	900	1.25	630
Green River above Jensen, Utah	-	-	-	-	2.0	50	2.0	6.12	0.75	800	1.2	600
Ashley Creek Basin	-	0.035	0.292	1.65	6.0	65	2.0	4.5	-	2,570	1.3	1,470
Duchesne River above Duchesne, Utah	0.16	0.35	0.12	-	2.0	50	2.0	5.0	10.0	1,590	1.6	1,590
Duchesne River above Randlett, Utah	-	-	0.08	-	1.0	55	2.0	6.9	9.5	1,470	1.25	410
White River Basin	0.25	0.55	3.15	-	2.0	65	1.0	6.0	3.0	1,590	1.3	390
Green River above Ouray, Utah	0.20	-	-	-	2.0	62	2.0	6.5	7.5	-	1.2	1,490
Price River Basin	0.25	-	0.80	1.5	2.0	55	2.0	5.0	8.0	5,600	1.0	940
Green River above Green River, Utah	0.17	-	-	-	2.0	62	2.0	6.5	-	-	1.25	1,400
San Rafael River Basin	-	0.20	0.20	-	5.0	55	2.0	7.0	3.8	4,350	1.25	1,670

Preceding page blank

C_s	C_{qa} (P.P.M.)	C_{oq} (P.P.M.)	m	n	Pot 5 (inches)	Pot 21 Model Year (inches)		Pot 28 Model Year (inches)		Pot 30 Model Year (inches)		Pot 24 Model Year (inches)		Delay A Agriculture (months)	Delay B Groundwater (months)
						1	2	1	2	1	2	1	2		
1.0	120	210	-1.02	15,592	2.10	2.24	1.68	0.30	0.30	0.06	0.08	2.5	3.5	3.5	2.0
1.25	320	600	-0.12	39.7	3.45	2.24	2.10	0.06	0.085	0.02	0.03	4.0	5.8	2.5	2.5
1.25	540	-	-	-	-	1.05	0.53	0.03	0.04	0.01	0.04	5.0	2.0	2.5	-
1.33	1,550	2,450	-0.97	31.0	0.41	0.57	0.25	0.04	0.18	0.01	0.05	1.8	3.3	2.75	2.0
1.25	660	-	-0.70	4,031	-	0.15	1.57	-	-	-	-	3.0	2.6	5.0	-
1.6	1,105	1,175	-0.39	1,425	1.31	0.4	1.80	0.02	0.044	0.06	0.06	0.5	0.4	3.0	3.5
1.25	1,500	-	-	-	2.1	2.22	0.25	0.08	0.195	-	-	3.2	4.1	2.5	-
1.5	700	700	-0.45	341	1.88	3.65	2.10	0.05	0.17	0.03	0.07	5.0	2.3	2.0	1.75
1.25	630	826	-0.97	17,432	3.21	5.2	2.5	0.09	0.04	0.03	0.07	4.6	2.8	2.75	2.5
1.2	600	590	-0.09	3.33	-	0.32	5.2	0.10	0.10	-	-	4.0	5.0	3.5	-
1.3	1,470	1,290	-0.17	91.1	1.50	0.13	3.3	-	0.04	0.06	0.06	2.57	1.80	6.0	5.5
.6	1,590	1,320	-0.76	3,643	2.68	3.80	1.18	0.075	0.03	0.04	0.08	3.5	1.7	3.5	2.5
.25	410	1,000	-0.57	1,808	2.5	3.65	1.14	0.09	0.14	0.08	0.06	4.2	7.0	2.0	2.0
.3	390	1,950	-0.66	1,723	2.13	1.5	3.7	0.08	0.08	0.02	0.02	3.0	5.7	3.5	2.5
.2	1,490	2,240	-	-	-	0.14	3.18	0.10	0.07	0.02	0.03	3.0	1.0	3.5	3.0
.0	940	5,050	-0.80	1,668	-	0.36	1.53	0.07	0.10	0.02	0.02	3.0	1.7	4.5	1.5
.25	1,400	-	-	-	-	0.04	0.52	0.06	0.0	-	-	3.0	0.4	-	-
.25	1,670	4,350	-0.53	569	1.80	0.0	1.51	0.02	0.01	0.05	0.02	0.9	0.8	2.5	2.5

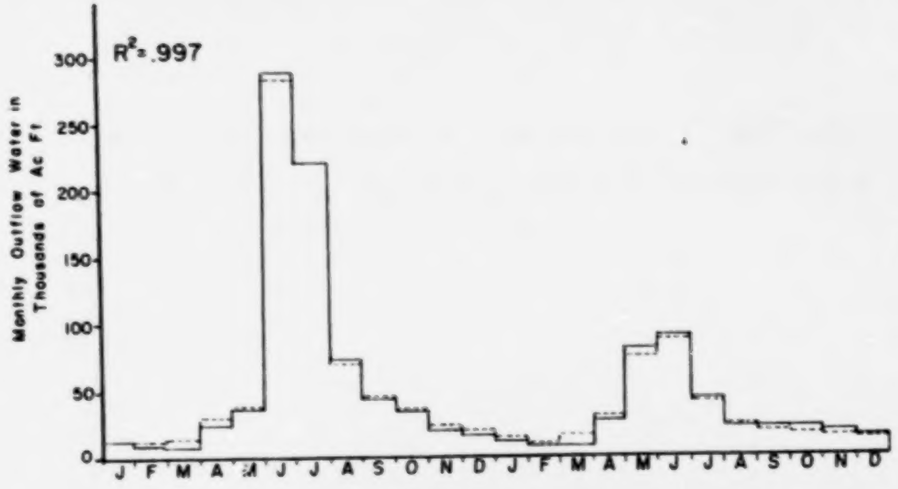
H-3- H-4

Table H-2. Single constant input parameters or coefficients for subbasins in the Grand Division.

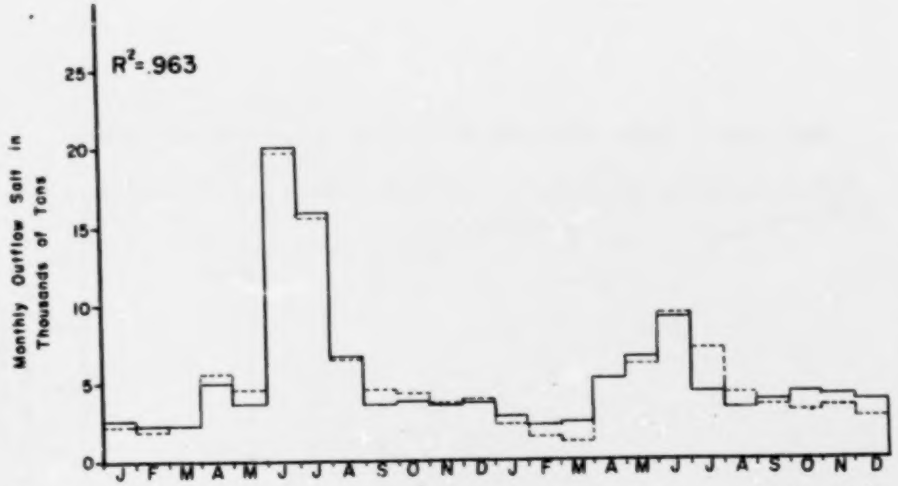
Subbasin	k_u	k_a	k_b	k_c	k_s	Efficiency (%)	M_{es} (inches)	M_{cs} (inches)	k_d (inches)	C_q (P.P.M.)	C_s	C_{qa} (P.P.M.)	C_{og} (P.P.M.)
Colorado River above Hot Sulphur Springs	0.32	-	2.5	-	2.0	40	2.0	6.0	-	320	1.25	75	-
Eagle River Basin	0.45	-	0.40	-	2.0	33	2.0	6.0	4.5	900	1.15	750	900
Colorado River above Glenwood Springs, Colorado	0.935	-	0.922	-	2.0	45	2.0	5.0	-	800	1.25	500	-
Roaring Fork River Basin	0.10	0.012	-	0.47	2.0	40	2.0	8.6	-	1,200	1.20	900	-
Colorado River above Plateau Creek	0.083	0.07	0.66	-	2.0	45	2.0	5.5	-	400	1.25	330	-
Plateau Creek Basin	0.80	-	-	0.35	2.0	57	2.0	5.0	-	-	1.24	500	-
Gunnison River above Gunnison, Colo.	0.37	0.26	1.00	-	2.0	30	2.0	6.0	4.7	370	1.25	160	380
Gunnison River above North Fork	0.27	0.071	1.90	-	2.0	45	2.0	5.0	-	400	1.25	330	-
Uncompahgre River Basin	0.40	0.484	0.50	-	2.0	32	2.0	6.4	7.0	-	1.25	3,300	2,200
Gunnison River above Grand Junction, Colorado	0.052	0.553	5.5	-	1.0	40	2.0	6.0	1.0	1,800	1.0	1,800	1,100
Colorado River above Colorado-Utah State Line	-	0.62	3.75	-	2.0	65	2.0	6.0	2.3	2,220	1.25	2,220	2,000
San Miguel River Basin	0.25	-	1.86	-	3.0	45	2.0	4.5	-	900	1.25	930	-
Dolores River Basin	0.16	0.50	5.0	-	2.0	66	2.0	5.3	-	2,800	1.25	700	-
Colorado River above Cisco, Utah	-	-	-	-	2.0	55	2.0	4.0	2.5	-	1.20	2,030	1,900

C_s	C_{qa} (P.P.M.)	C_{og} (P.P.M.)	m	n	Pot 5 (inches)	Pot 21 Model Year (inches)		Pot 28 Model Year (inches)		Pot 30 Model Year (inches)		Pot 24 Model Year (inches)		Delay A Agriculture (months)	Delay B Groundwater (months)
						1	2	1	2	1	2	1	2		
1.25	75	-	-0.09	30.7	-	3.23	2.50	0.01	.0355	-	-	4.0	5.2	2.0	-
1.15	750	900	-0.77	2,500	-	2.05	0.38	0.06	0.19	0.06	0.15	5.0	6.0	2.5	3.0
1.25	500	-	-0.28	15.4	-	1.69	0.90	0.20	0.26	-	-	3.6	3.7	3.0	-
1.20	900	-	-0.38	181.5	3.64	0.65	3.60	5.2	7.9	-	-	7.6	7.9	2.0	-
1.25	330	-	-0.14	11.5	3.8	0.81	1.26	0.10	0.05	-	-	4.0	4.2	3.0	-
1.24	500	-	-	-	-	0.63	0.32	0.07	0.045	-	-	4.3	4.45	3.0	-
1.25	160	380	-0.04	24.0	2.1	0.96	3.14	0.08	0.10	0.05	0.06	5.4	5.7	2.5	3.0
1.25	330	-	-0.14	11.5	3.8	0.81	1.26	0.10	0.05	-	-	4.0	4.2	3.0	-
1.25	3,300	2,200	-	-	2.50	0.78	1.42	0.08	0.077	0.14	0.17	4.0	5.8	4.0	2.0
1.0	1,800	1,100	-0.67	2,565	2.42	1.49	0.30	0.13	0.17	0.02	0.02	4.4	6.0	2.0	2.0
.25	2,220	2,000	-0.90	25,542	1.50	0.29	0.65	1.35	1.95	0.04	0.04	5.1	6.0	2.5	3.0
.25	930	-	-1.00	2,800	-	0.49	2.84	0.03	0.03	-	-	3.4	3.0	3.0	-
.25	700	-	-1.00	9,800	1.60	0.14	2.00	0.027	0.0	-	-	3.0	1.8	2.5	-
.20	2,030	1,900	-	-	-	0.0	0.30	0.03	0.02	2.5	4.0	3.0	1.0	3.5	-

H-5. H-6

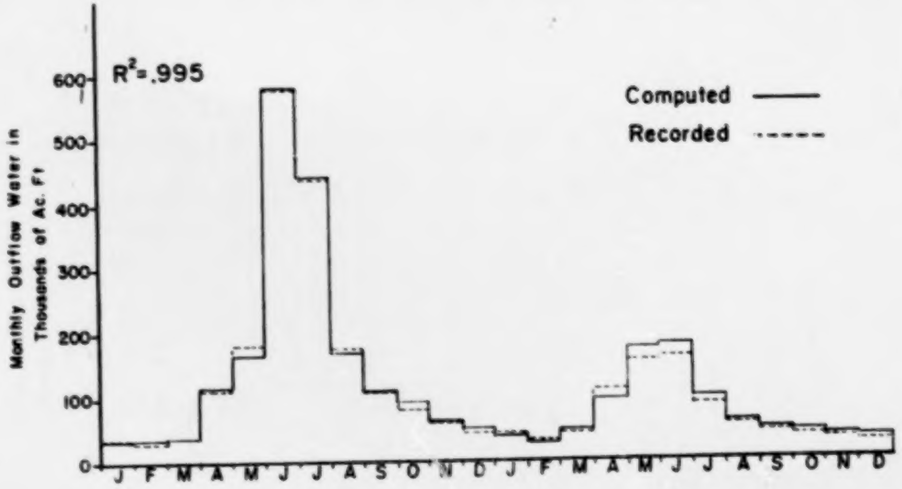


Runoff Hydrograph - New Fork River Basin 1965-1966

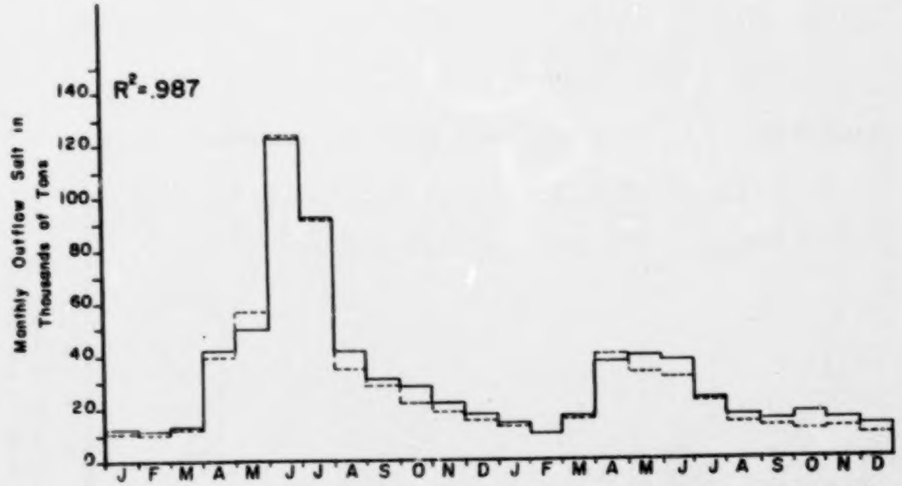


Salt Outflow - New Fork River Basin 1965-1966

Figure H1. Computed and recorded water and salt outflow graphs of the New Fork River basin.



Runoff Hydrology - Green River Above LaBarge 1965-1966



Salt Outflow - Green River Above LaBarge 1965-1966

Figure H2. Computed and recorded water and salt outflow graphs of Green River above LaBarge.

Table I-1. Hydrologic and salinity inputs to the management study basin–without proposed project 1964.

Month	Gaged surface water inflow (acre-feet)			Sub-surface inflow	Precipitation correlation	Input salinity concentration	Precipitation	Temperature	Percent daylight hours x 5	Scaled crop-growth stage coefficient			Canal diversion	Percentage interchange based on outflow	Recorded surface water outflow San Juan River at Shiprock (acre-feet)	Recorded salt outflow
	San Juan River at Archuleta	Animas River	LaPlata River									phreatophyte				
				(acre-feet)		(tons/in.)	(inches)	(°F)		k_{c_1}'	k_{c_2}	k_c	(acre-feet)			(tons)
Jan.	17,390	10,020	111	950		1,055	0.094	(27.5)	(35)					44	31,260	25,200
	(3.1)	(1.8)	(–)	(.2)	(3)	(87.9)	(1.88)			(54.1)	(10.8)	(2.7)			(5.5)	(7.0)
Feb.	13,190	9,330	133	750		1,034	0.112	(30.6)	(34)					55	22,750	20,160
	(2.3)	(1.6)	(–)	(.1)	(7)	(86.2)	(2.24)			(63.7)	(11.7)	(3.5)			(4.0)	(5.6)
Mar.	12,750	10,250	63	700		1,073	0.646	(37.7)	(42)					62	22,060	20,520
	(2.2)	(1.8)	(–)	(.1)	(8)	(89.4)	(12.92)			(70.2)	(14.9)	(4.6)			(3.9)	(5.7)
Apr.	14,530	15,960	86	700		949	1.246	(48.6)	(44)				15,000	65	20,530	19,080
	(2.6)	(2.8)	(–)	(.1)	(8)	(79.1)	(24.92)			(79.8)	(16.9)	(5.5)	(7.8)		(3.6)	(5.3)
May	33,860	98,310	23	700		480	0.17	(61.6)	(49)				30,000	11	108,200	42,120
	(6.0)	(17.3)	(–)	(.1)	(8)	(40.0)	(3.40)			(86.4)	(18.2)	(5.6)	(15.6)		(19.1)	(11.7)
June	81,900	68,930	13	950		528	0.006	(69.7)	(49)				26,500	9	130,700	53,280
	(14.4)	(12.1)	(–)	(.2)	(5)	(44.0)	(0.12)			(89.2)	(18.8)	(5.6)	(13.7)		(23.0)	(14.8)
July	107,900	16,390	37	1,400		648	0.79	(77.3)	(50)				22,500	11	111,500	67,680
	(19.0)	(2.9)	(–)	(.2)	(18)	(54.0)	(15.8)			(87.9)	(18.8)	(5.7)	(11.8)		(19.6)	(18.8)
Aug.	48,000	27,750	1,770	1,650		870	1.04	(72.5)	(47)				13,200	11	110,500	104,400
	(8.5)	(4.9)	(.3)	(.3)	(47)	(72.5)	(20.8)			(86.4)	(18.2)	(5.7)	(6.8)		(19.5)	(29.0)
Sept.	26,150	11,570	119	1,700		864	1.838	(64.9)	(42)				12,000	34	37,780	37,440
	(4.6)	(2.0)	(–)	(.3)	(22)	(72.0)	(36.76)			(79.8)	(17.5)	(5.5)	(6.3)		(6.7)	(10.4)
Oct.	28,280	8,910	26	1,600		720	0	(55.9)	(39)				10,500	49	28,530	24,840
	(5.0)	(1.6)	(–)	(.3)	(3)	(60.0)	(0)			(73.3)	(15.7)	(5.5)	(4.5)		(5.0)	(6.9)
Nov.	20,590	12,010	45	1,300		955	0.934	(38.9)	(34)					38	33,580	32,040
	(3.6)	(2.1)	(–)	(.2)	(16)	(79.6)	(18.68)			(63.7)	(13.6)	(4.0)			(5.9)	(8.9)
Dec.	32,200	14,410	77	1,050		866	1.154	(29.9)	(34)					25	52,280	41,400
	(5.7)	(2.5)	(–)	(.2)	(11)	(72.2)	(23.08)			(54.1)	(11.0)	(3.0)			(9.2)	(11.5)

Figures in parenthesis are scaled values which were input to the computer program.

Table I-2. Hydrologic and salinity inputs to the management study basin–without proposed project 1965.

Month	Gaged surface water inflow (acre-feet)			Sub-surface inflow	Precipitation correlation	Input salinity concentration	Precipitation	Temperature	Percent daylight hours x 5	Scaled crop-growth stage coefficient			Canal diversion	Percentage interchange based on outflow outflow	Recorded surface water outflow San Juan River at Shiprock (acre-feet)	Recorded salt outflow
	San Juan River at Archuleta	Animas River	LaPlata River									phreatophyte				
				(acre-feet)		(tons/in.)	(inches)	(°F)		k_{c_1}	k_{c_2}	k_c	(acre-feet)			(tons)
Jan.	90,220	15,350	230	800		700	0.742	(33.3)	(35)	(54.1)	(10.8)	(2.7)		46	114,300	60,840
	(15.9)	(2.7)	(–)	(.1)	(22)	(58.3)	(14.84)								(20.1)	(16.9)
Feb.	92,230	13,310	530	750		710	0.634	(34.0)	(34)	(63.7)	(11.7)	(3.5)		39	108,200	53,640
	(16.2)	(2.3)	(.1)	(.1)	(10)	(59.2)	(12.68)								(19.1)	(14.9)
Mar.	51,860	18,700	540	700		877	0.314	(41.7)	(42)	(70.2)	(14.9)	(4.6)		46	79,350	48,960
	(9.1)	(3.3)	(.1)	(.1)	(4)	(73.1)	(6.28)								(14.0)	(13.6)
Apr.	85,110	71,360	6,390	750		715	1.088	(51.0)	(44)	(79.8)	(16.9)	(5.5)	15,000	38	148,600	68,760
	(15.0)	(12.6)	(1.1)	(.1)	(10)	(59.6)	(21.76)						(7.8)		(26.2)	(19.1)
May	138,300	150,600	3,820	850		527	0.922	(58.4)	(49)	(86.4)	(18.2)	(5.6)	30,000	36	273,500	92,880
	(24.4)	(26.5)	(.7)	(.1)	(24)	(43.9)	(18.44)						(15.6)		(48.2)	(25.8)
June	215,100	236,300	2,830	1,350		383	0.996	(66.4)	(49)	(89.2)	(18.8)	(5.6)	26,500	41	437,900	114,120
	(37.9)	(41.6)	(.5)	(.2)	(29)	(31.9)	(19.92)						(13.7)		(77.1)	(31.7)
July	101,900	181,700	890	2,300		384	1.79	(75.6)	(50)	(87.9)	(18.8)	(5.7)	22,500	38	292,200	96,120
	(18.0)	(32.0)	(.2)	(.4)	(36)	(32.0)	(35.8)						(11.8)		(51.5)	(26.7)
Aug.	136,200	72,520	1,860	3,550		582	0.96	(73.2)	(47)	(86.4)	(18.2)	(5.7)	13,200	45	206,100	104,760
	(24.0)	(12.8)	(.3)	(.6)	(29)	(48.5)	(19.2)						(6.8)		(36.3)	(29.1)
Sept.	112,200	55,660	560	4,500		517	1.136	(63.1)	(42)	(79.8)	(17.5)	(5.5)	12,000	47	159,000	62,280
	(19.8)	(9.8)	(.1)	(.8)	(26)	(43.1)	(72.72)						(6.3)		(28.0)	(17.3)
Oct.	131,000	43,200	670	4,800		461	1.47	(54.9)	(39)	(73.3)	(15.7)	(5.5)	10,500	42	169,100	63,360
	(23.1)	(7.6)	(.1)	(.8)	(26)	(38.4)	(29.4)						(4.5)		(29.8)	(17.6)
Nov.	179,600	28,960	1,260	4,500		468	1.146	(45.9)	(34)	(63.7)	(13.6)	(4.0)		41	209,800	71,640
	(31.6)	(5.1)	(.2)	(.8)	(21)	(39.0)	(22.92)								(37.0)	(19.9)
Dec.	177,400	25,460	1,890	3,700		514	1.288	(34.7)	(34)	(54.1)	(11.0)	(3.0)		42	210,300	81,360
	(31.3)	(4.5)	(.3)	(.7)	(28)	(42.8)	(25.76)								(37.1)	(2.6)

Figures in parenthesis are scaled values which were input to the computer program.

Table I-3. Hydrologic and salinity inputs to the management study area–without proposed project 1931-60.

Month	Gaged surface water inflow (acre-feet)			Sub-surface inflow	Precipitation correlation	Input salinity concentration	Precipitation	Temperature	Percent daylight hours x 5	Scaled crop-growth stage coefficient			Canal diversion	Percentage interchange based on outflow	Recorded surface water outflow San Juan River at Shiprock (acre-feet)	Recorded salt outflow
	San Juan River at Archuleta	Animas River	LaPlata River									phreatophyte				
				(acre-feet)		(tons/in.)	(inches)	(°F)		k_{c_1}	k_{c_2}	k_c	(acre-feet)			(tons)
Jan.	12,100 (2.1)	15,280 (2.7)	870 (.2)	1,400 (.2)	(10)	972 (81)	0.51 (10.2)	(29.1)	(34)	(54.1)	(10.8)	(2.7)		45	28,300 (5.0)	25,560 (7.1)
Feb.	12,900 (2.3)	15,160 (2.7)	1,280 (.2)	1,200 (.2)	(13)	984 (82)	0.56 (11.2)	(35.2)	(35)	(63.7)	(11.7)	(3.5)		32	34,300 (6.0)	25,920 (7.2)
Mar.	18,500 (3.3)	24,710 (4.4)	1,670 (.3)	1,100 (.2)	(12)	936 (78)	0.57 (11.4)	(42.2)	(42)	(70.2)	(14.9)	(4.6)		27	46,300 (8.2)	30,240 (8.4)
Apr.	100,200 (17.7)	60,240 (10.6)	4,130 (.7)	1,100 (.2)	(10)	816 (68)	0.54 (10.8)	(51.5)	(44)	(79.8)	(16.9)	(5.5)	15,000 (7.8)	6	180,000 (31.7)	79,200 (22.0)
May	224,000 (39.5)	142,420 (25.1)	4,610 (.8)	1,200 (.2)	(14)	552 (46)	0.52 (10.4)	(60.3)	(49)	(86.4)	(18.2)	(5.6)	30,000 (15.6)	3	354,500 (62.5)	120,600 (33.5)
June	247,200 (43.6)	172,280 (30.4)	2,290 (.4)	1,500 (.3)	(7)	576 (48)	0.34 (6.8)	(69.6)	(49)	(89.2)	(18.8)	(5.6)	26,500 (13.7)	29	409,500 (72.2)	141,120 (39.2)
July	169,800 (29.9)	60,860 (10.7)	480 (.1)	2,200 (.4)	(19)	864 (72)	0.84 (16.8)	(75.6)	(50)	(87.9)	(18.9)	(5.7)	22,500 (11.8)	55	222,000 (39.1)	112,320 (31.2)
Aug.	121,400 (21.4)	25,930 (4.6)	720 (.1)	2,600 (.5)	(28)	1,044 (87)	1.07 (21.4)	(73.5)	(47)	(86.4)	(18.2)	(5.7)	13,200 (6.8)	85	146,300 (25.8)	121,680 (33.8)
Sept.	87,000 (15.3)	20,100 (3.5)	780 (.1)	2,800 (.5)	(19)	1,008 (84)	0.86 (17.2)	(65.8)	(42)	(79.8)	(17.5)	(5.5)	12,000 (6.3)	10	109,400 (19.3)	68,760 (19.1)
Oct.	41,800 (7.4)	26,680 (4.7)	1,910 (.3)	2,700 (.5)	(19)	1,032 (86)	0.89 (17.8)	(53.4)	(39)	(73.3)	(15.7)	(5.5)	10,500 (4.5)	15	74,600 (13.1)	48,240 (13.4)
Nov.	14,600 (2.6)	19,470 (3.4)	600 (.1)	2,300 (.4)	(9)	900 (75)	0.42 (8.4)	(39.5)	(34)	(63.7)	(13.6)	(4.0)		33	36,000 (6.3)	30,600 (8.5)
Dec.	12,700 (2.2)	16,170 (2.8)	580 (.1)	1,700 (.3)	(12)	912 (76)	0.58 (11.6)	(30.2)	(34)	(54.1)	(11.0)	(3.0)		45	30,400 (5.6)	27,360 (7.6)

Figures in parenthesis are scaled values which were input to the computer program.

Table I-4. Hydrologic and salinity inputs to the management study area–with proposed project 1931-60.

Month	Gaged surface water inflow (acre-feet)			Sub-surface inflow	Precipi-tation correlation	Input salinity concentration	Precipi-tation	Temp-erature	Percent daylight hours x 5	Scaled crop-growth Stage Coefficient			Canal diversion	Percentage interchange based on outflow	Recorded surface water outflow San Juan River at Shiprock	Recorded salt outflow
	San Juan River Archuleta	Animas River	LaPlata River									phreato-phyte				
				(acre-feet)		(tons/in.)	(inches)	(°F)		k_{c_1}	k_{c_2}	k_c	(acre-feet)		(acre-feet)	(tons)
Jan.	12,100	15,280	870	1,400		5,472	0.51							41	39,300	46,100
	(1.1)	(1.4)	(.1)	(.1)	(10)	(76)	(10.2)	(29.1)	(34)	(35)	(18)	(0.5)			(7.4)	(11.9)
Feb.	12,900	15,160	1,280	1,200		5,544	0.56							40	37,200	42,800
	(1.2)	(1.4)	(.1)	(.1)	(13)	(77)	(11.2)	(35.2)	(35)	(41)	(20)	(0.6)			(7.0)	(11.9)
Mar.	18,500	24,710	1,670	1,100		5,256	0.57							27	47,900	45,000
	(1.7)	(2.3)	(.2)	(.1)	(12)	(73)	(11.4)	(42.2)	(42,	(45)	(24)	(0.8)			(9.0)	(12.5)
Apr.	100,200	60,240	4,130	1,100		4,608	0.54						46,000	85	142,600	82,800
	(9.4)	(5.7)	(.4)	(.1)	(10)	(64)	(10.8)	(51.5)	(44)	(51)	(28)	(1.0)	(4.3)		(26.8)	(23.0)
May	224,000	142,420	4,610	1,200		3,024	0.32						134,000	38	299,000	108,000
	(21.0)	(13.4)	(.4)	(.1)	(14)	(42)	(10.4)	(60.3)	(49)	(55)	(34)	(1.0)	(12.6)		(56.2)	(30.0)
June	247,200	172,280	2,290	1,500		3,168	0.34						168,500	34	330,900	123,500
	(23.2)	(16.2)	(.2)	(.1)	(7)	(44)	(6.8)	(69.6)	(49)	(57)	(49)	(1.0)	(15.8)		(62.2)	(34.3)
July	169,800	60,860	480	2,200		4,896	0.84						166,500	95	128,200	87,100
	(16.0)	(5.7)	(–)	(.2)	(19)	(68)	(16.8)	(75.6)	(50)	(56)	(52)	(1.0)	(15.6)		(24.1)	(24.2)
Aug.	121,400	25,930	720	2,600		5,904	1.07						127,200	12	88,300	76,300
	(11.4)	(2.4)	(.1)	(.2)	(28)	(82)	(21.4)	(73.5)	(47)	(55)	(47)	(1.0)	(12.0)		(16.6)	(21.2)
Sept.	87,000	20,100	780	2,800		5,688	0.86						84,000	17	75,000	64,800
	(8.2)	(1.9)	(.1)	(.3)	(19)	(79)	(17.2)	(65.8)	(42)	(51)	(43)	(1.0)	(7.9)		(14.1)	(18.0)
Oct.	41,800	26,680	1,910	2,700		5,832	0.89						35,500	19	67,600	58,300
	(3.9)	(2.5)	(.2)	(.3)	(.9)	(81)	(17.8)	(53.4)	(39)	(47)	(25)	(1.0)	(3.3)		(12.7)	(16.2)
Nov.	14,600	19,470	600	2,300		5,040	0.42							25	51,600	45,000
	(1.4)	(1.8)	(.1)	(.2)	(9)	(70)	(9.4)	(39.5)	(34)	(41)	(22)	(0.7)			(9.7)	(12.5)
Dec.	12,700	16,170	580	1,700		5,112	0.58							29	41,000	38,900
	(1.2)	(1.5)	(.1)	(.2)	(12)	(71)	(11.6)	(30.2)	(34)	(35)	(19)	(0.5)			(7.7)	(10.8)

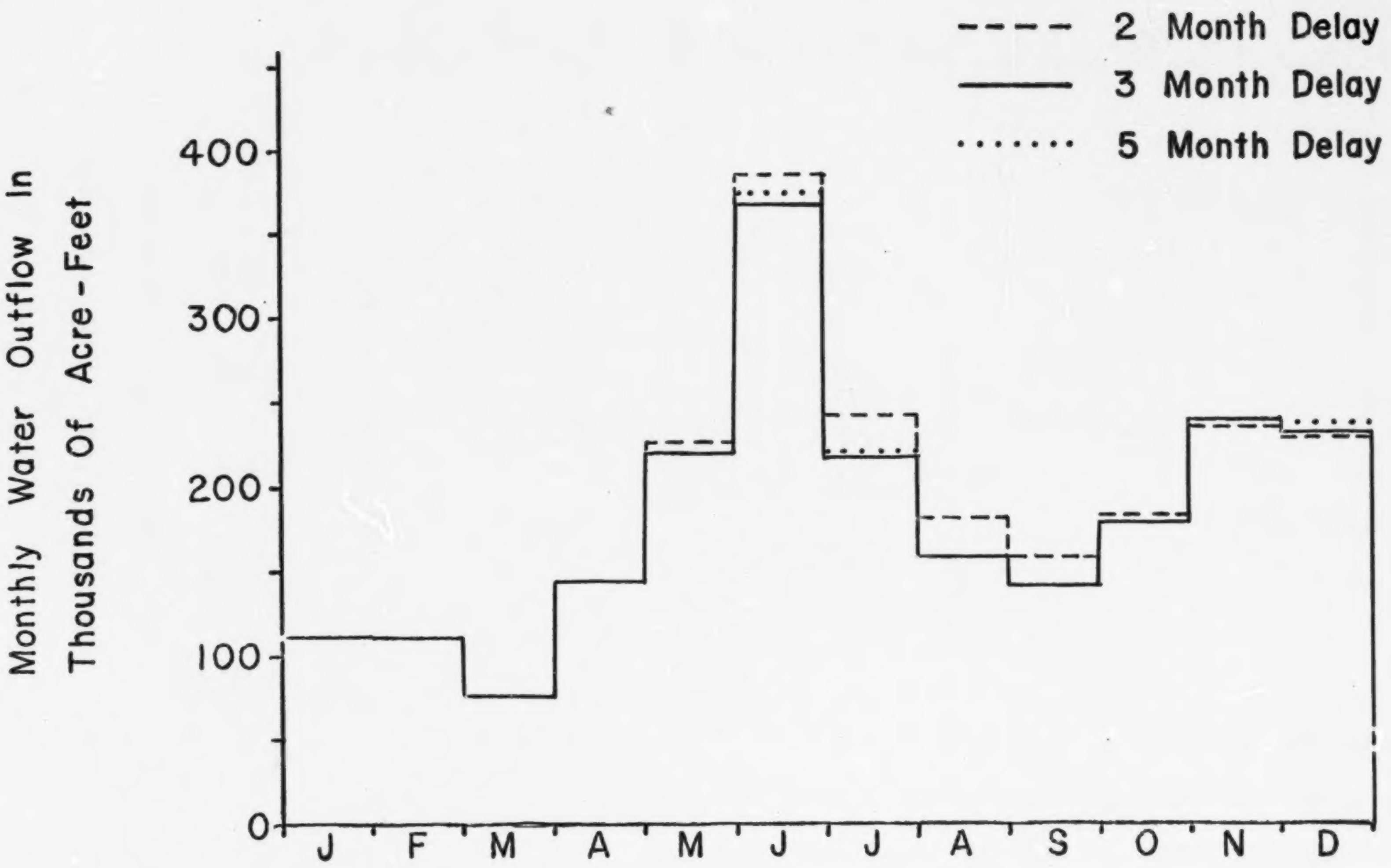


Figure 11. The effects on the water outflow hydrograph of 1965 from changing the rate of return of the deep percolating water to the surface system.

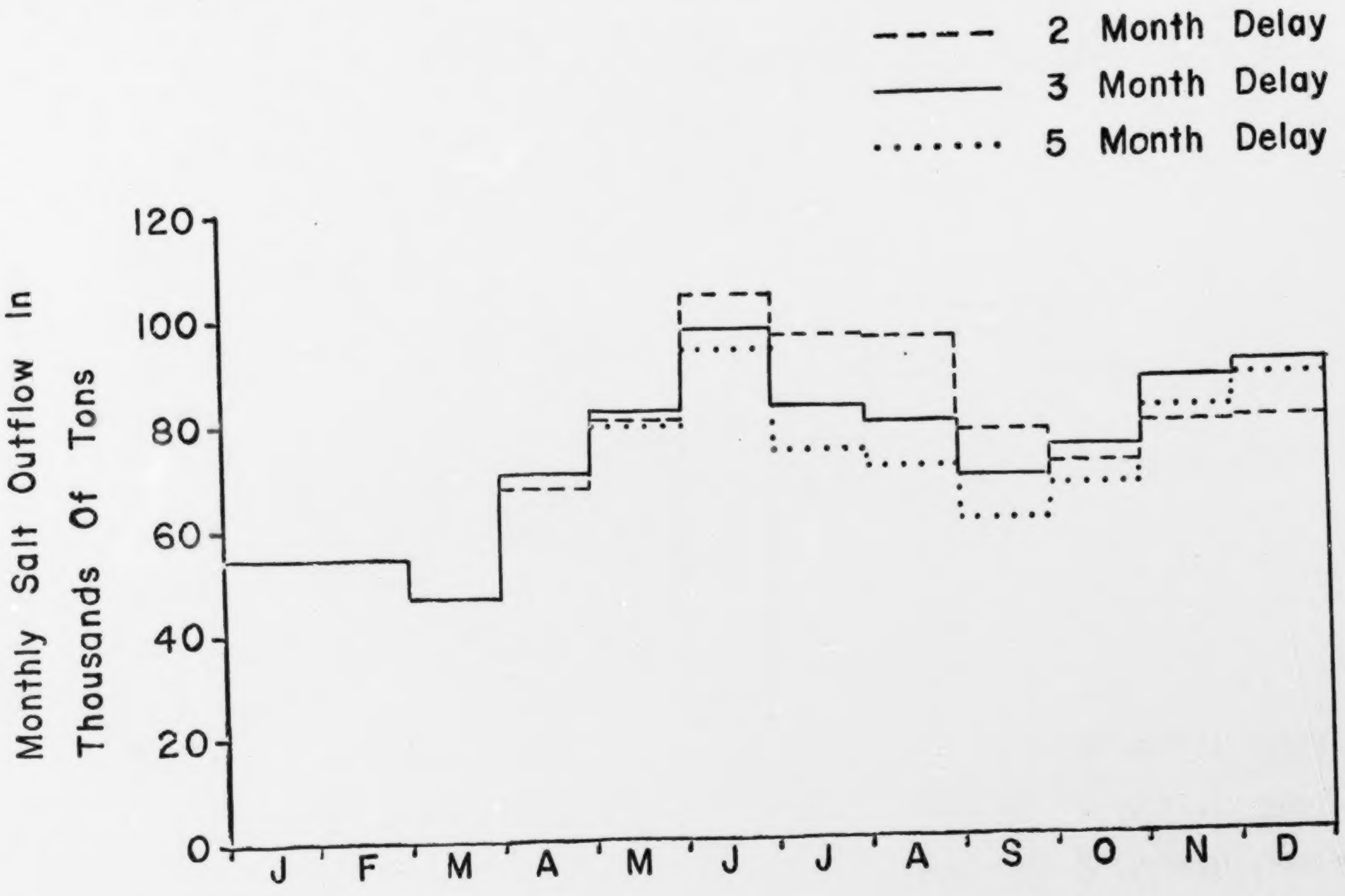


Figure I2. The effects on the salt outflow hydrograph of 1965 from changing the rate of return of the deep percolating water to the surface systems.

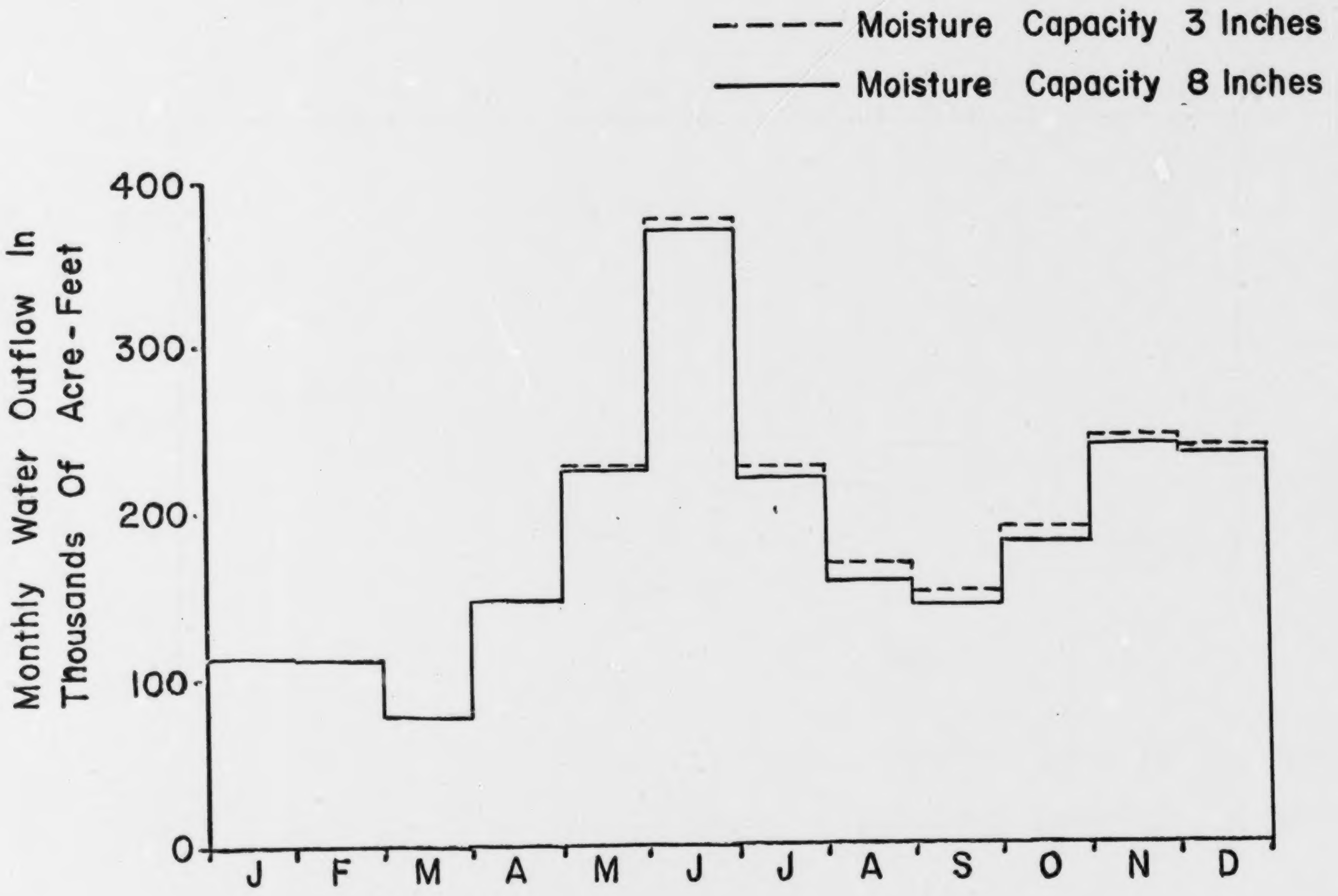


Figure 13. The effects on the water outflow hydrograph of 1965 from changing the soil moisture capacity of the proposed irrigation project.

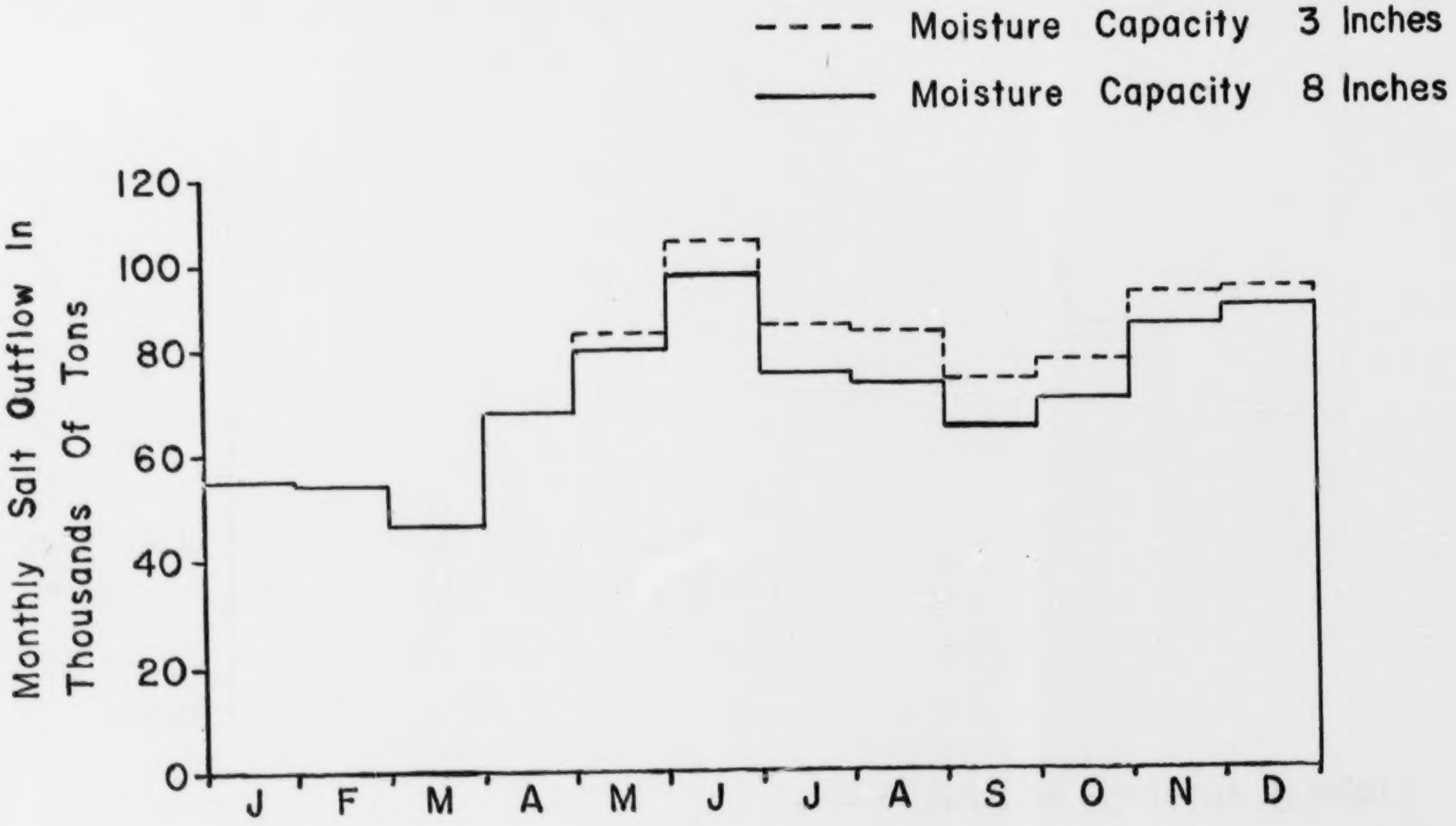


Figure 14. The effects on the salt outflow hydrograph of 1965 from changing the soil moisture capacity of the proposed irrigation project.

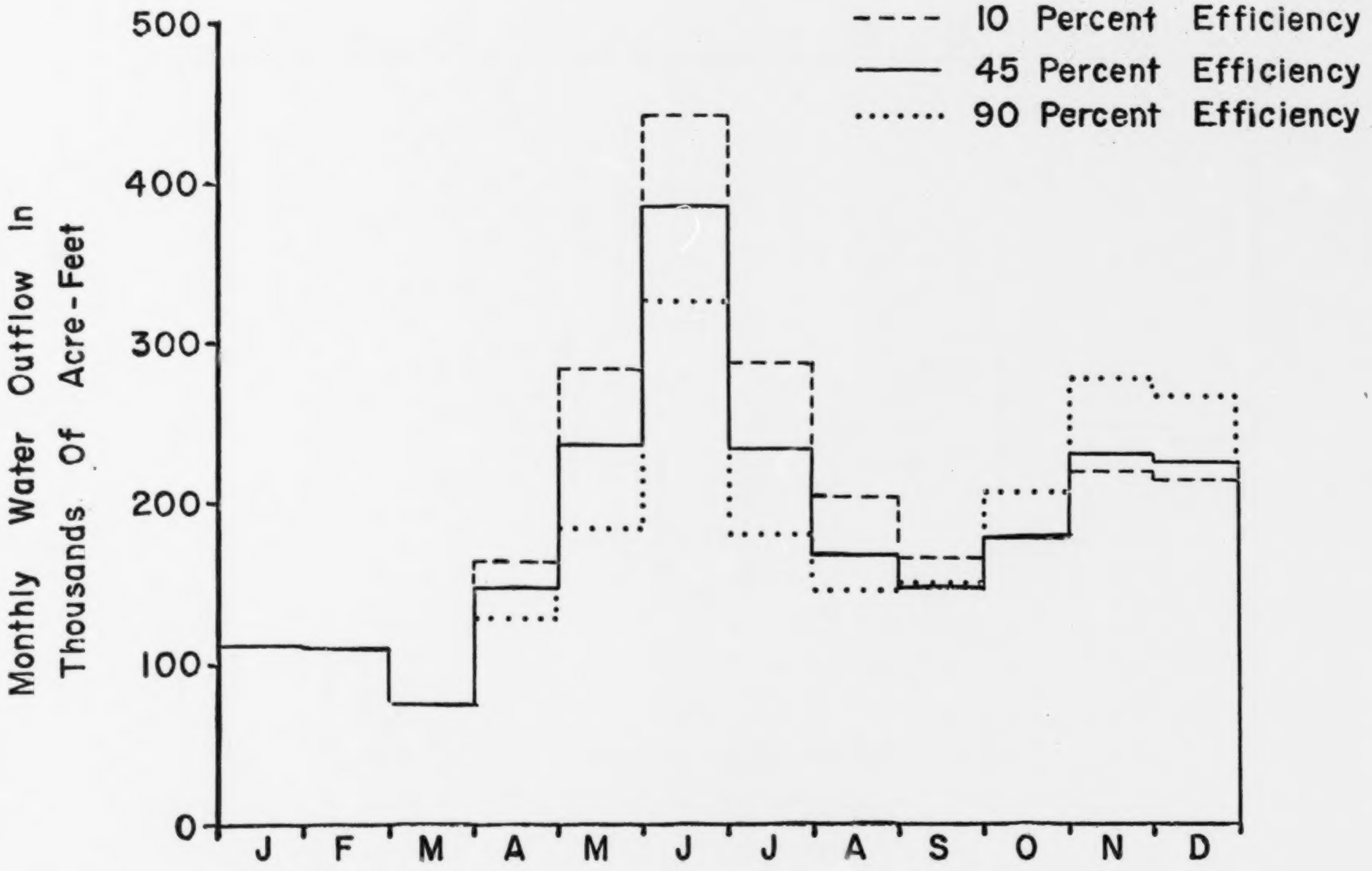


Figure I5. Effects on the water outflow hydrograph of 1965 from varying irrigation efficiency of the proposed project.

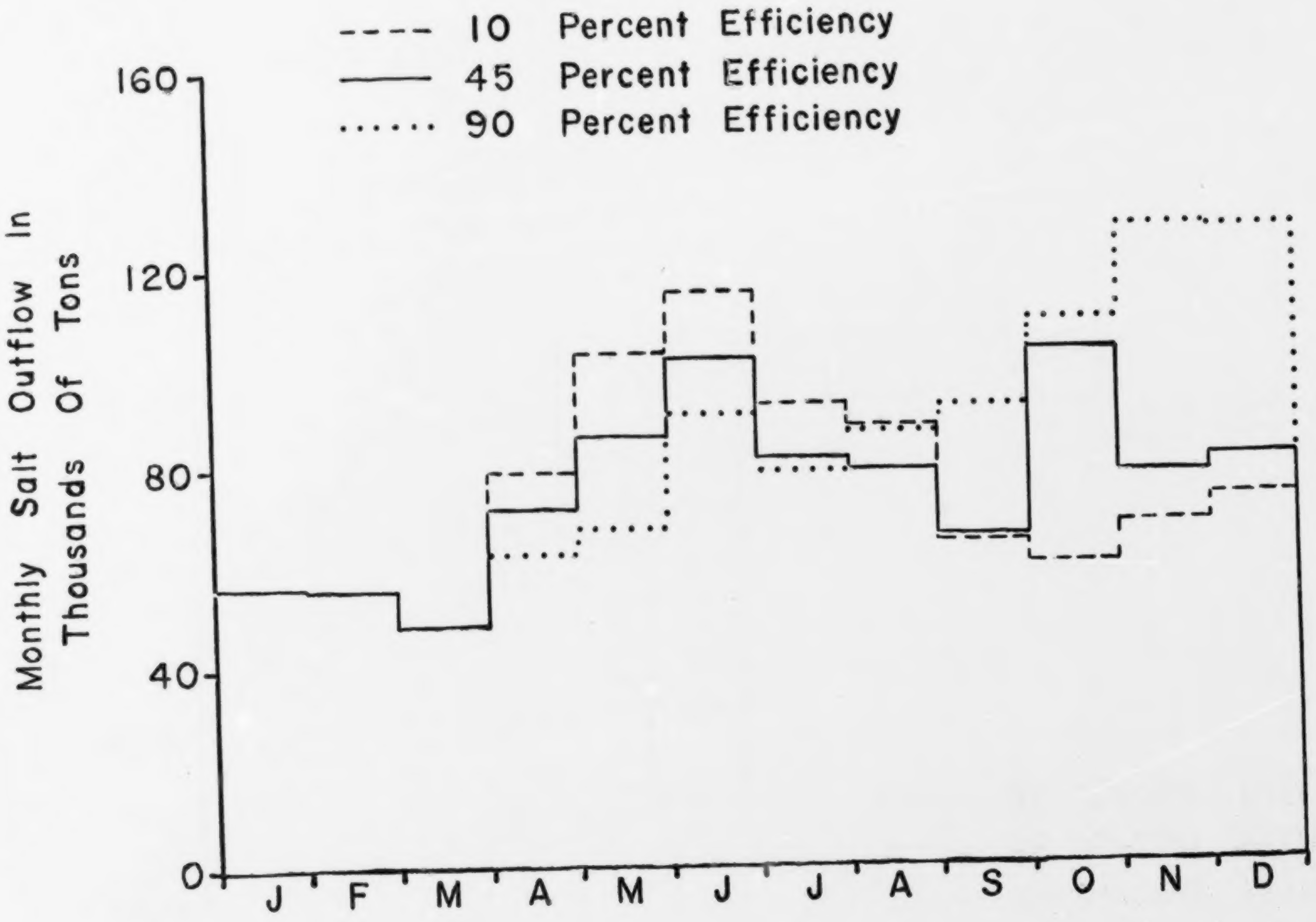
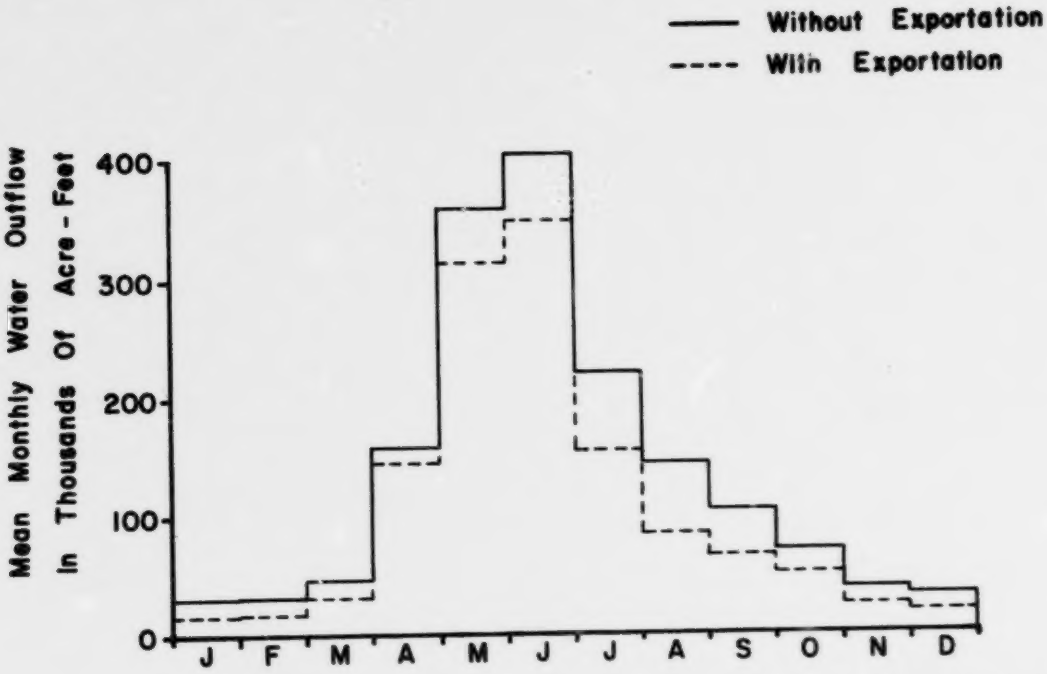


Figure 16. Effects on the salt outflow hydrograph of 1965 from varying irrigation efficiency of the proposed project.



Mean 1931-1960 water outflow hydrograph with and without the exportation of New Mexico's allocated share of Colorado River water.

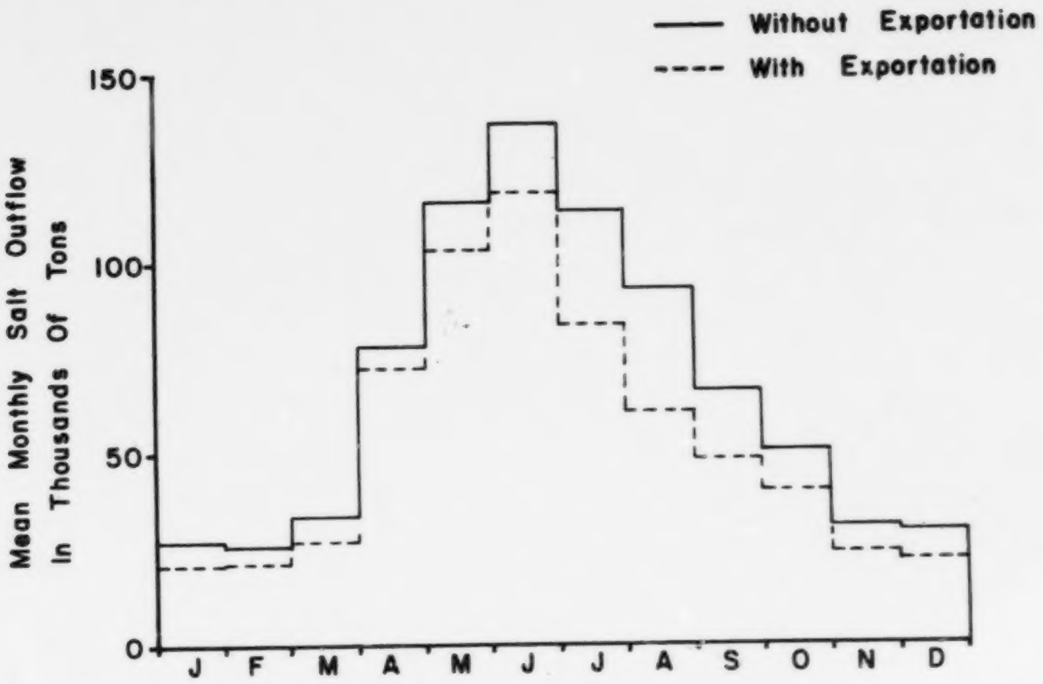
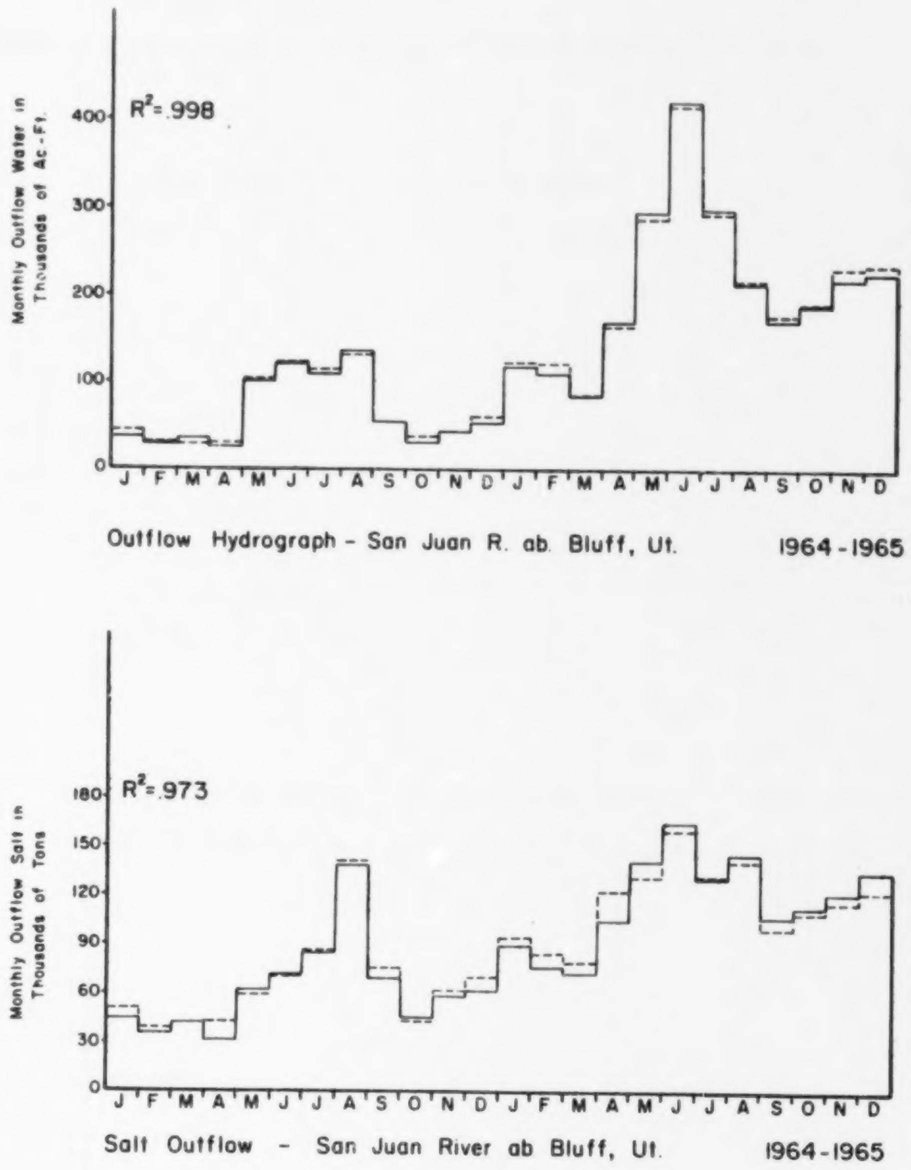


Figure 17. Mean 1931-1960 salt outflow hydrograph with and without the exportation of New Mexico's allocated share of Colorado River water.

APPENDIX I

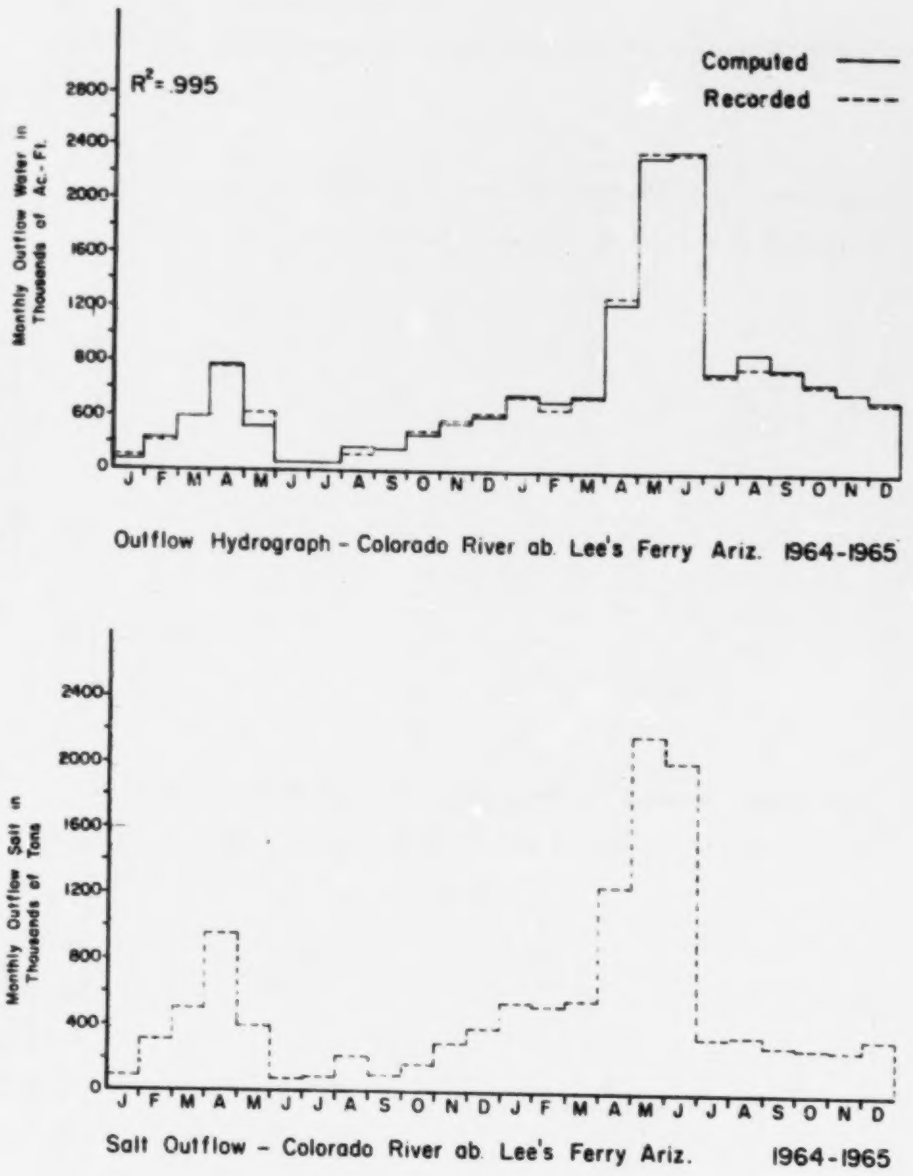
Management Study



Outflow Hydrograph - San Juan R. ab. Bluff, Ut. 1964-1965

Salt Outflow - San Juan River ab Bluff, Ut. 1964-1965

Figure H39. Computed and recorded water and salt outflow graphs of the San Juan River above Bluff, Utah.



Outflow Hydrograph - Colorado River ab. Lee's Ferry Ariz. 1964-1965

Salt Outflow - Colorado River ab. Lee's Ferry Ariz. 1964-1965

Figure H40. Computed and recorded water and salt outflow graphs of the Colorado River above Lee Ferry, Arizona.

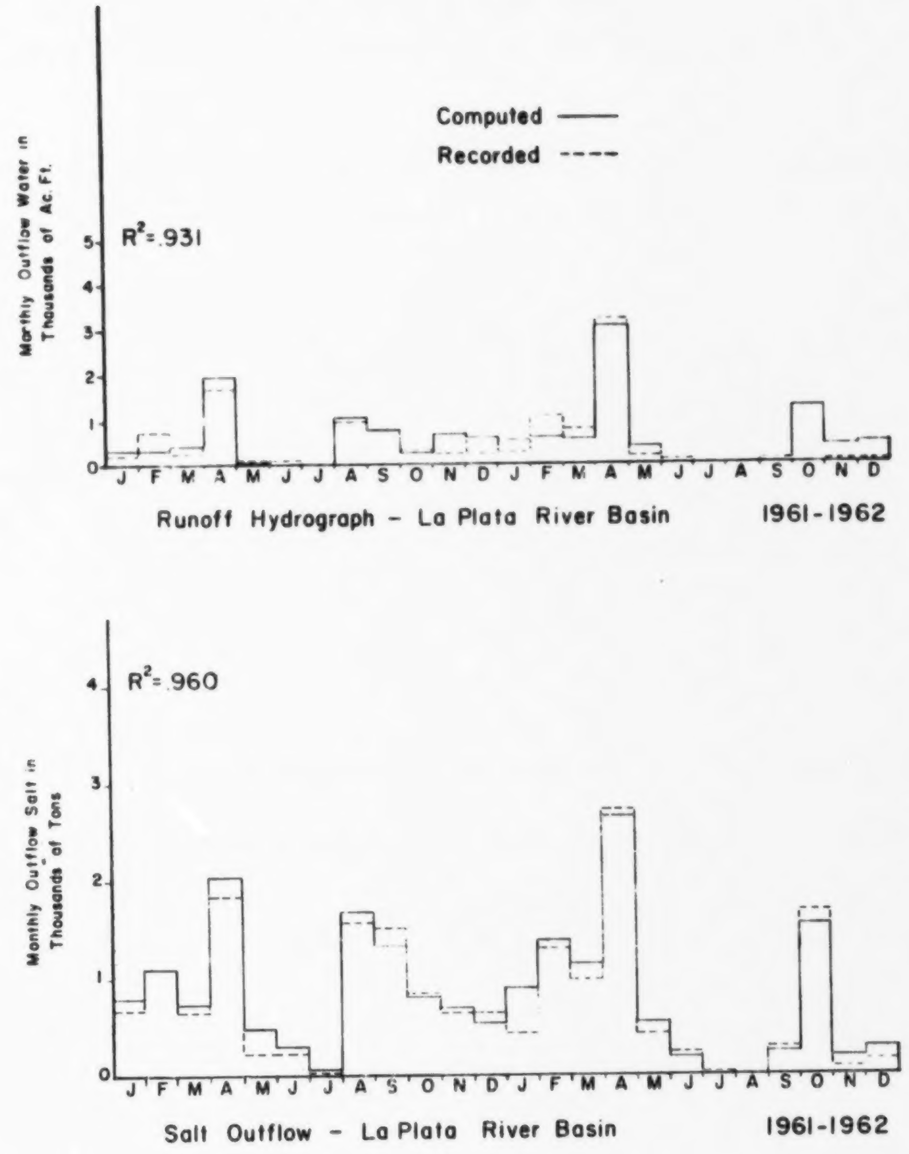


Figure H37. Computed and recorded water and salt outflow graphs of the La Plata River basin.

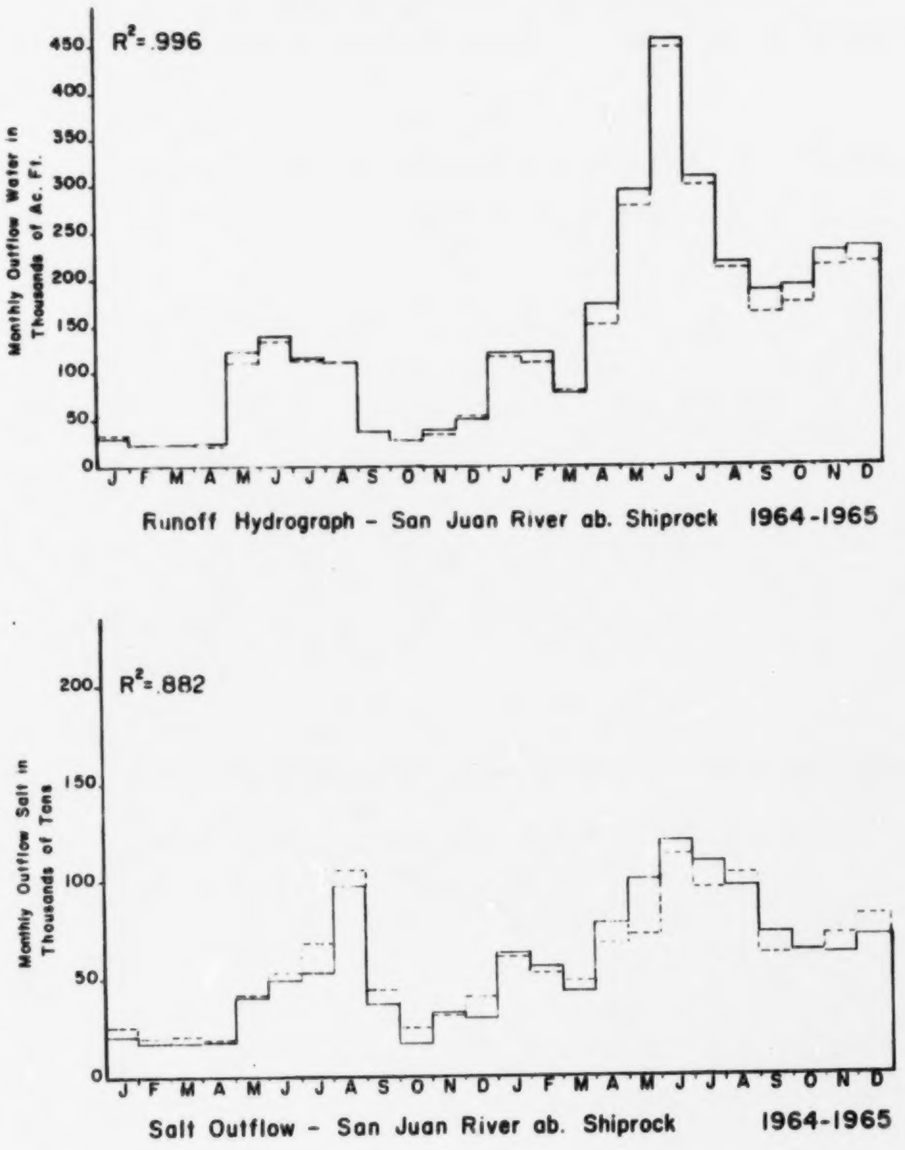


Figure H38. Computed and recorded water and salt outflow graphs of the San Juan River above Shiprock.

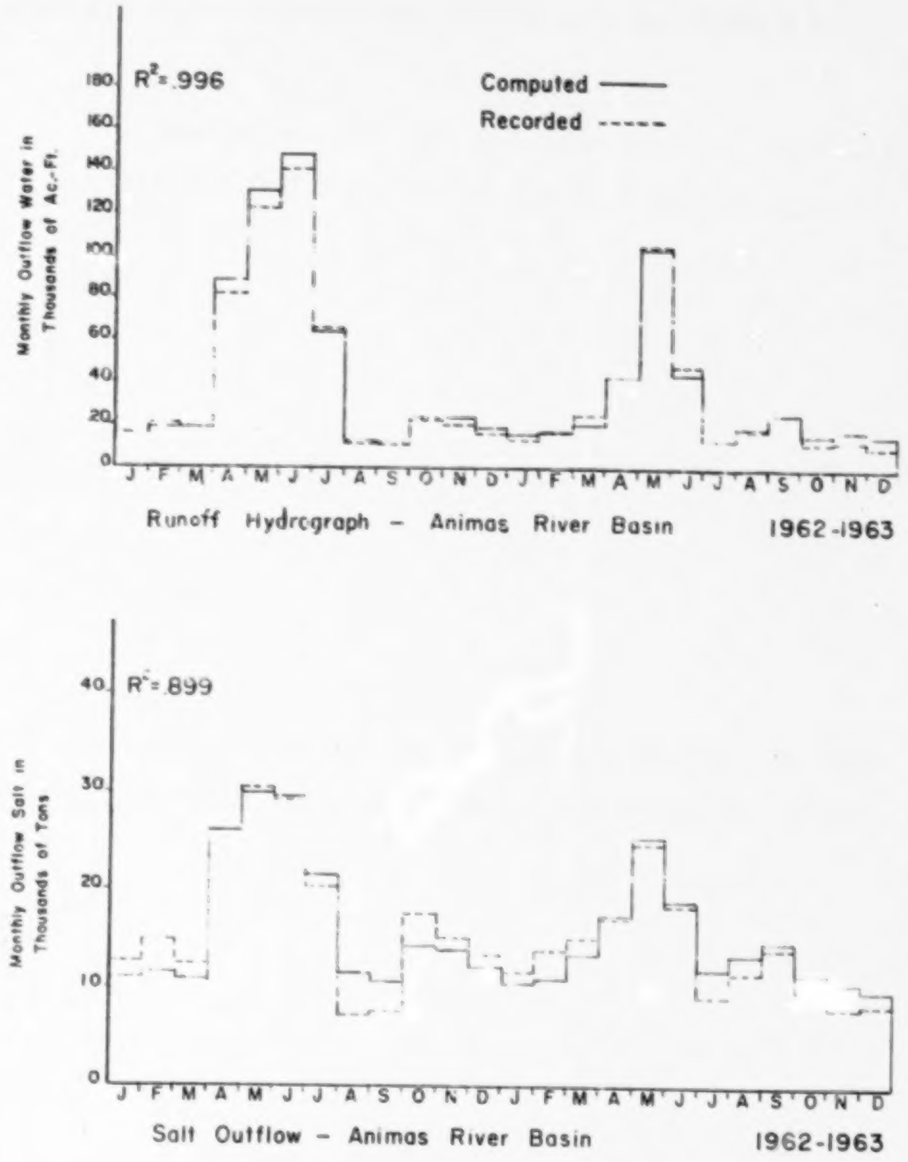


Figure H35. Computed and recorded water and salt outflow graphs of the Animas River basin.

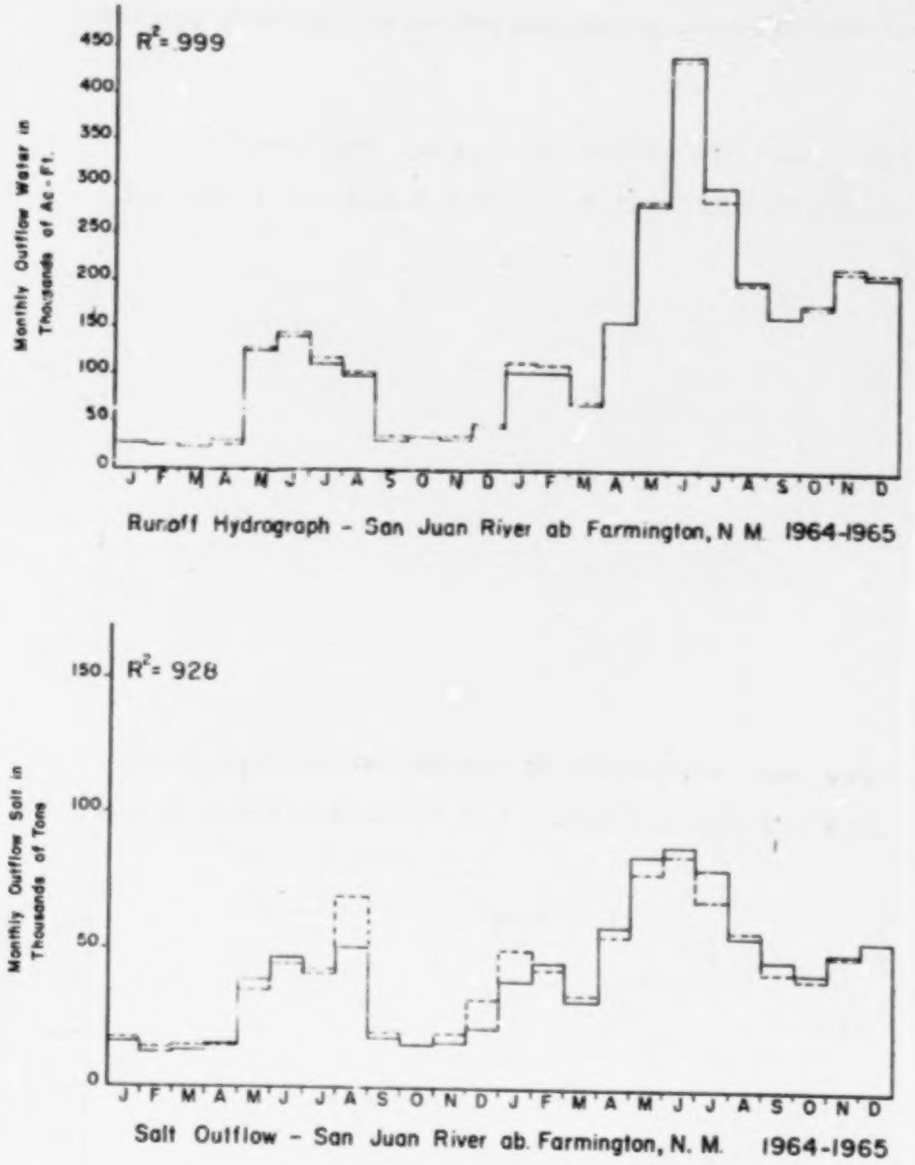
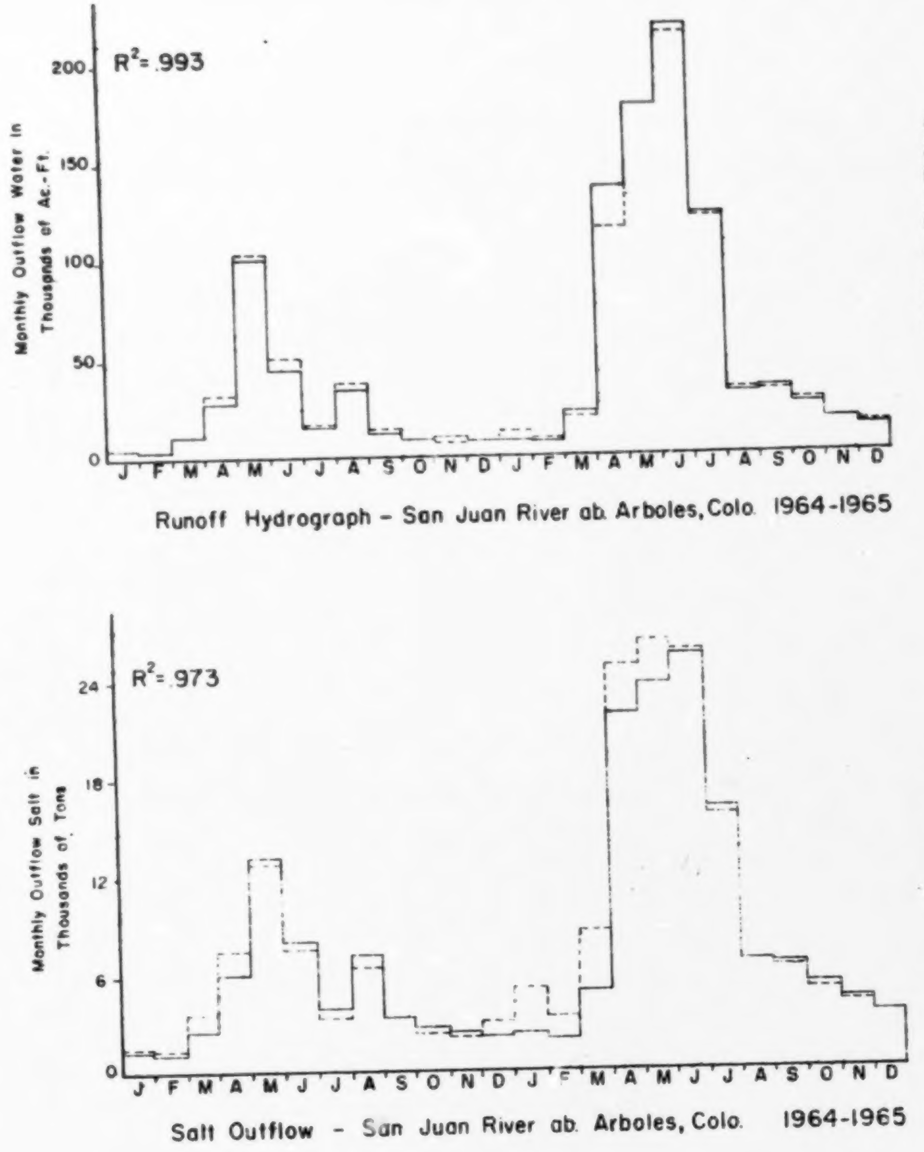


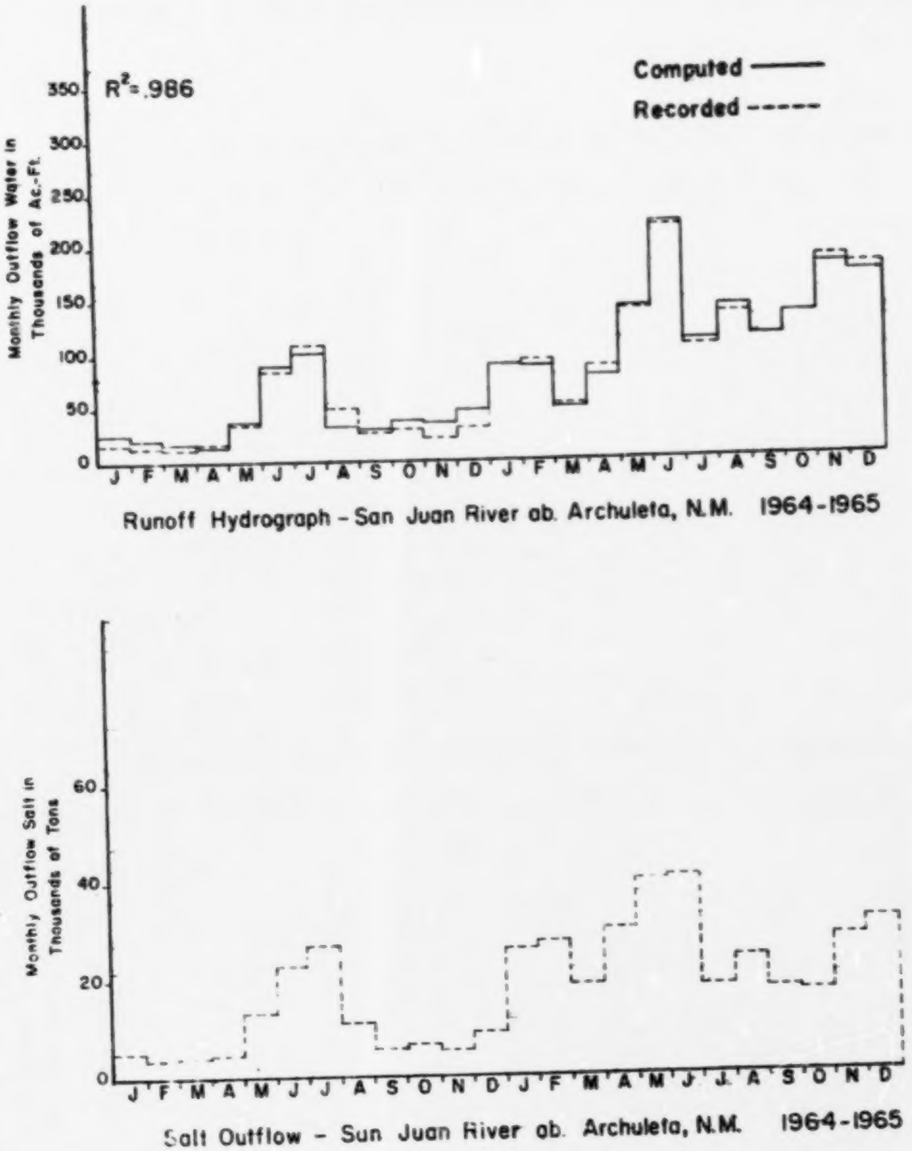
Figure H36. Computed and recorded water and salt outflow graphs of the San Juan River above Farmington, New Mexico.



Runoff Hydrograph - San Juan River ab. Arboles, Colo. 1964-1965

Salt Outflow - San Juan River ab. Arboles, Colo. 1964-1965

Figure H33. Computed and recorded water and salt outflow graphs of the San Juan River above Arboles, Colorado.



Runoff Hydrograph - San Juan River ab. Archuleta, N.M. 1964-1965

Salt Outflow - Sun Juan River ab. Archuleta, N.M. 1964-1965

Figure H34. Computed and recorded water and salt outflow graphs of the San Juan River above Archuleta, New Mexico.

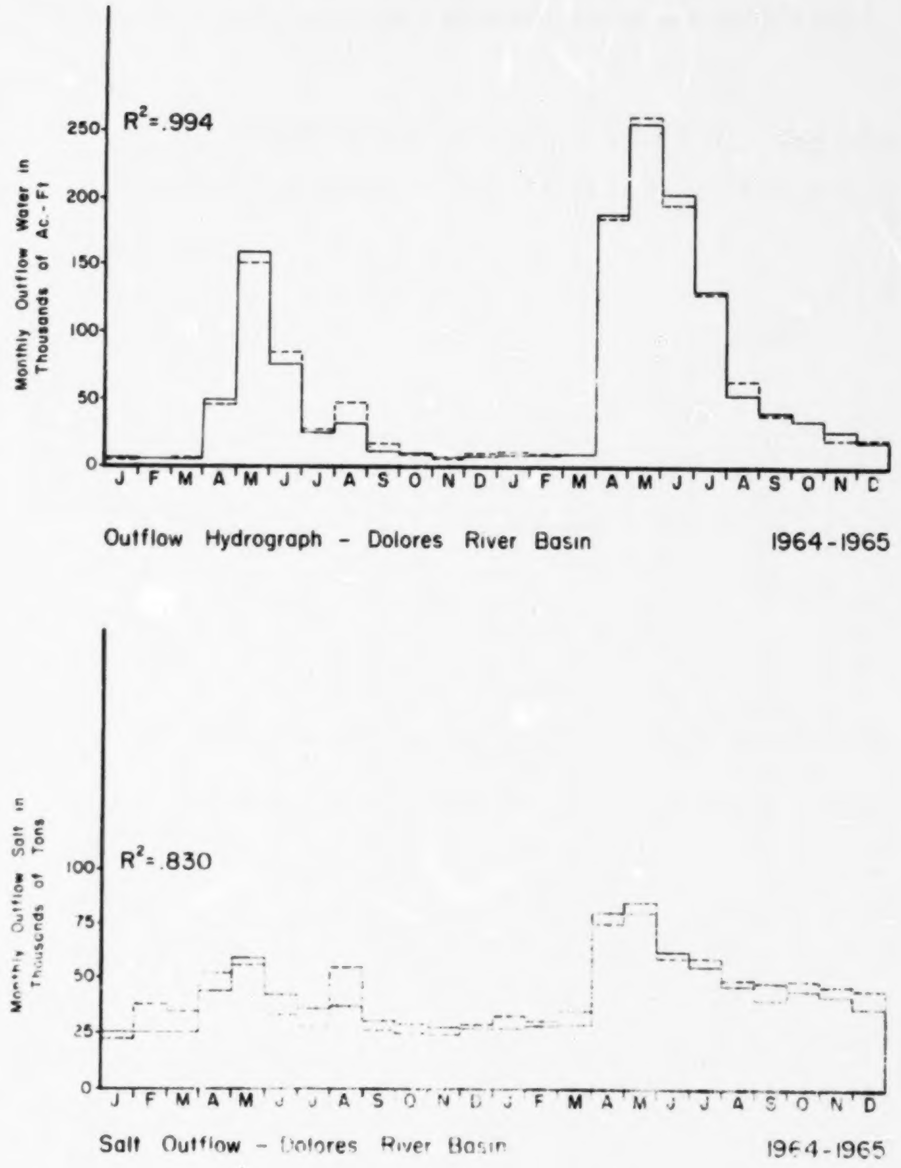


Figure H31. Computed and recorded water and salt outflow graphs of the Dolores River basin.

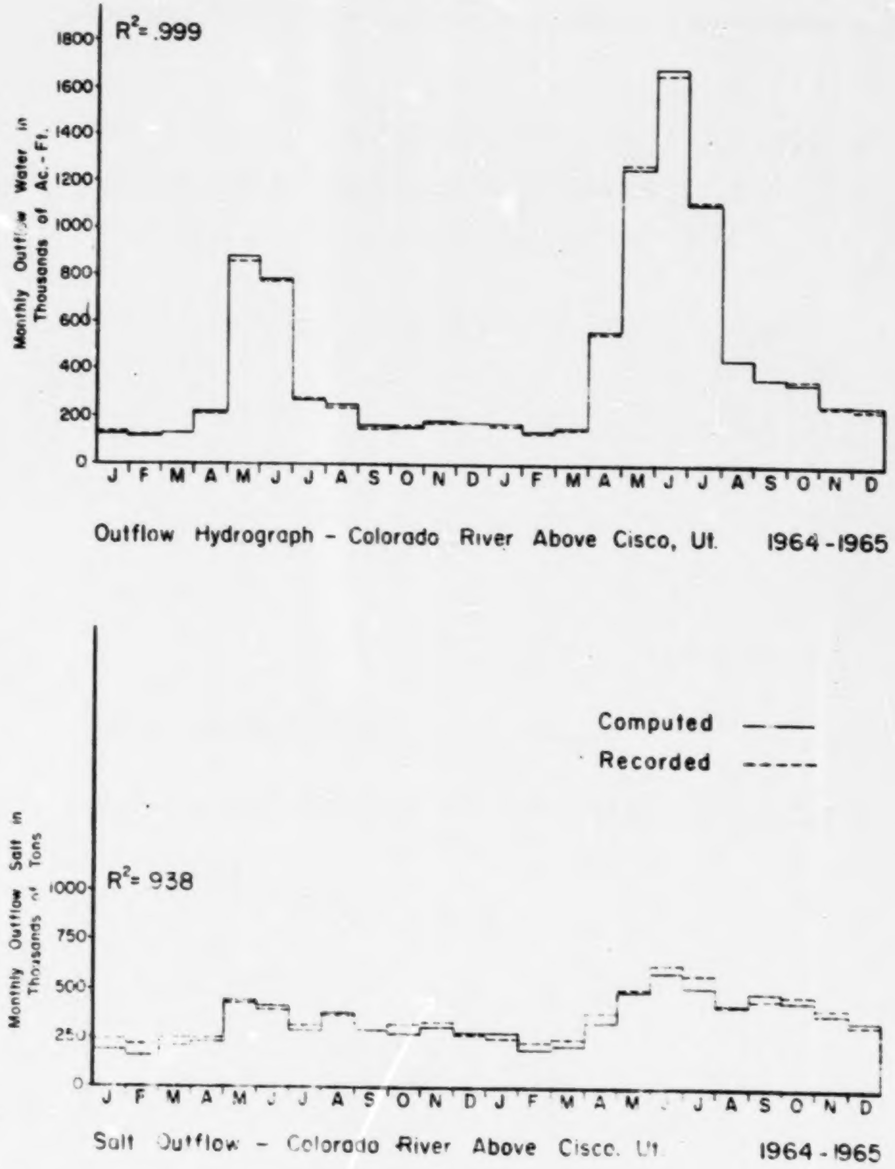
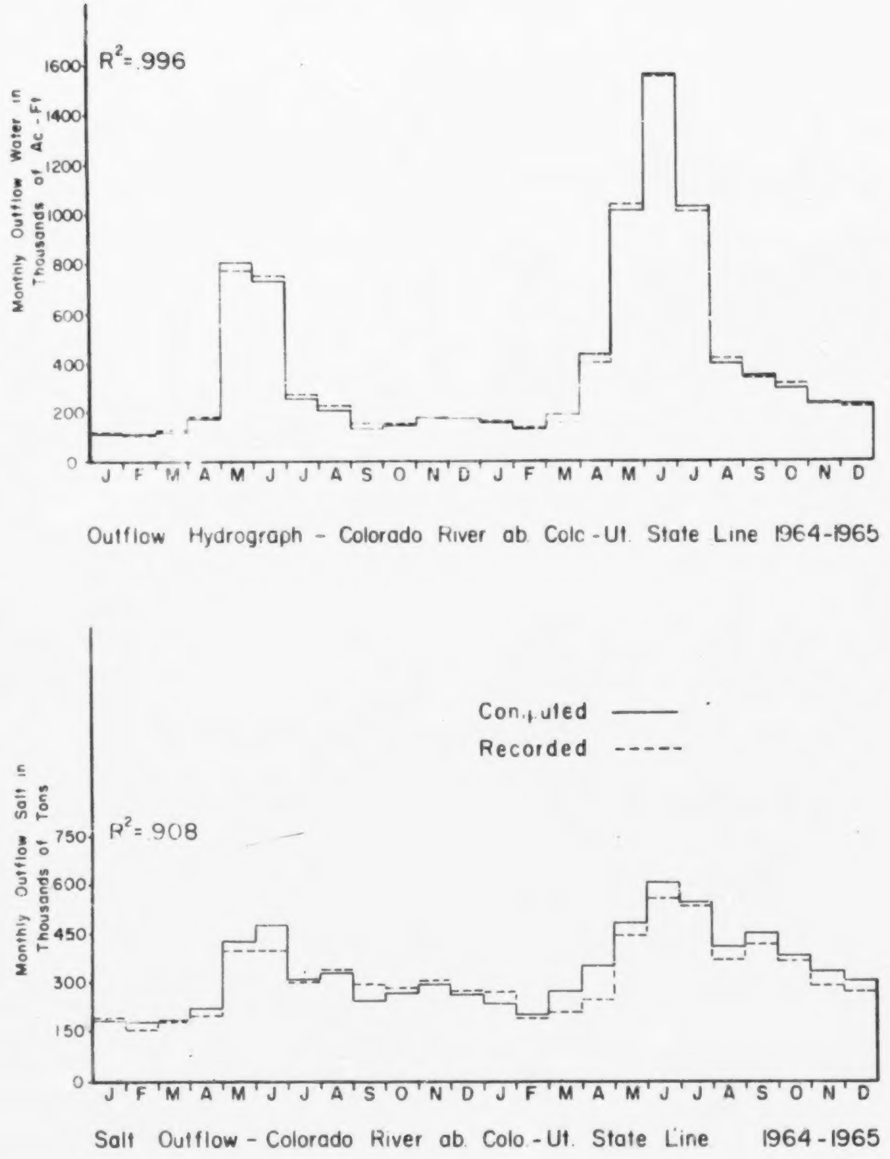
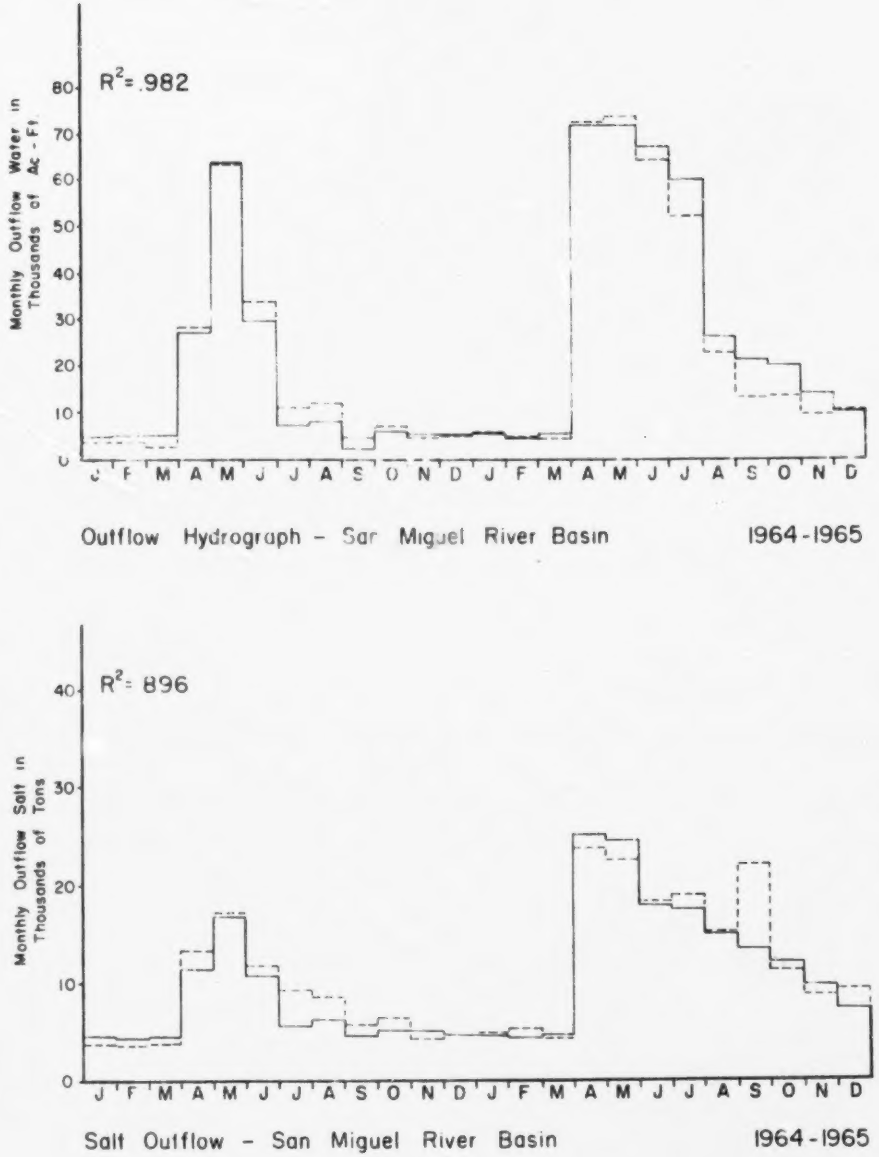


Figure H32. Computed and recorded water and salt outflow graphs of the Colorado River above Cisco, Utah.


Outflow Hydrograph - Colorado River ab. Colo - Ut. State Line 1964-1965

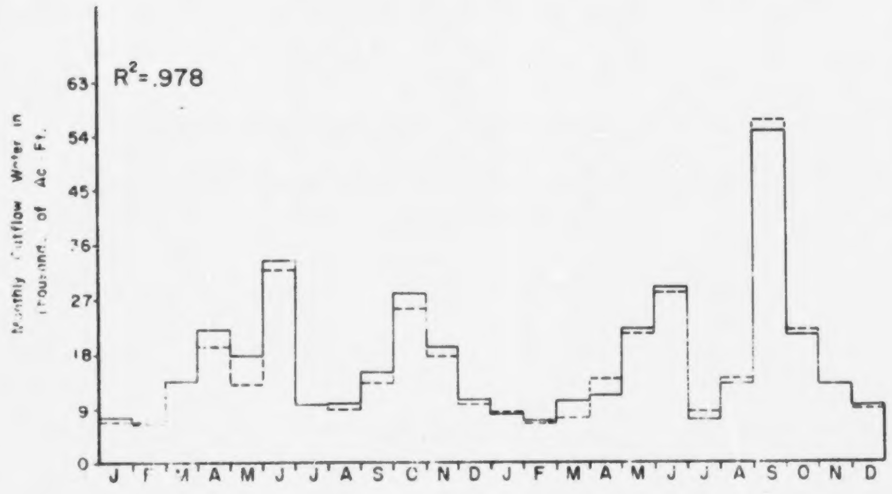
Salt Outflow - Colorado River ab. Colo.-Ut. State Line 1964-1965

Figure H29. Computed and recorded water and salt outflow graphs of the Colorado River above Colorado - Utah State Line.

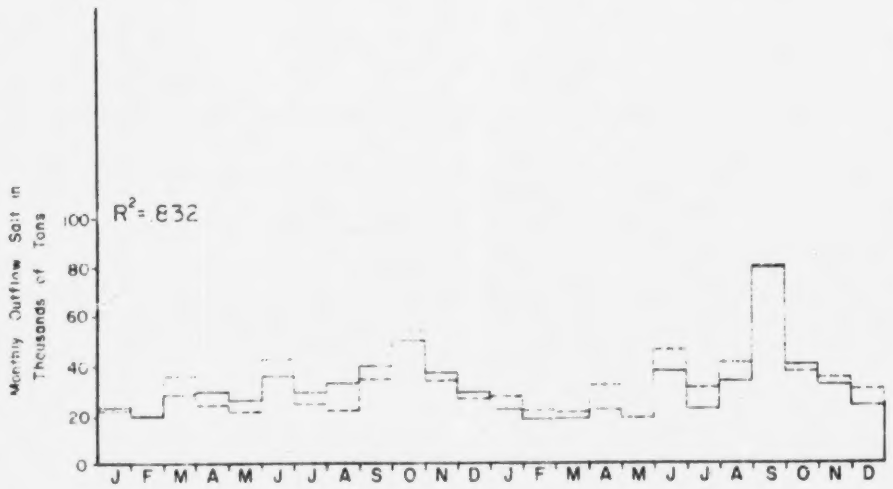

Outflow Hydrograph - San Miguel River Basin 1964-1965

Salt Outflow - San Miguel River Basin 1964-1965

Figure H30. Computed and recorded water and salt outflow graphs of the San Miguel River basin.

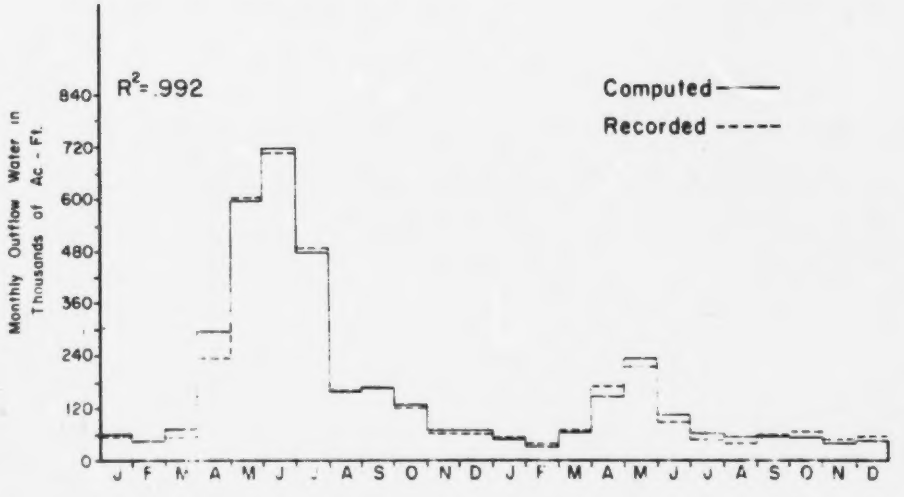


Runoff Hydrograph – Uncompahgre River Basin 1960-1961

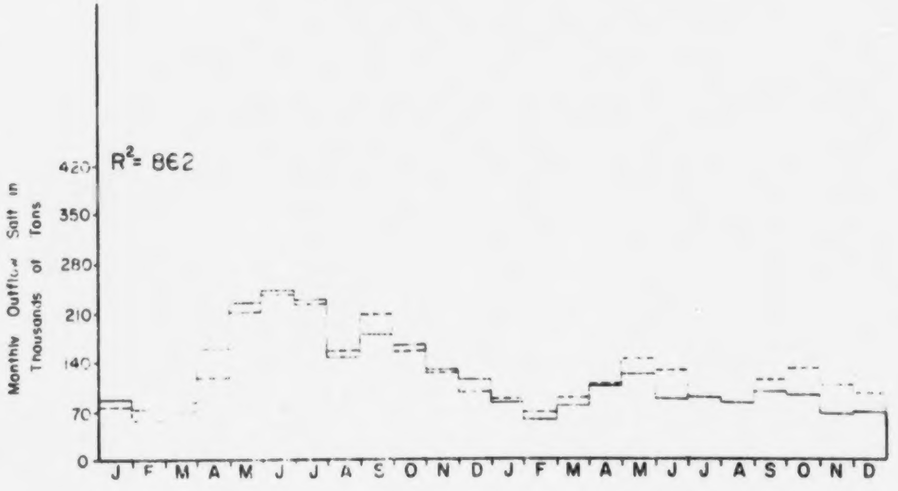


Salt Outflow – Uncompahgre River Basin 1960-1961

Figure H27. Computed and recorded water and salt outflow graphs of the Uncompahgre River basin.

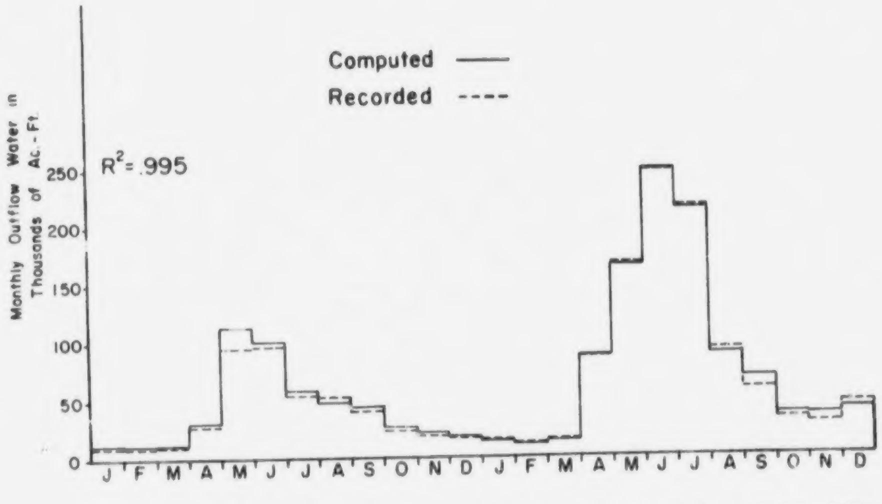


Runoff Hydrograph – Gunnison River ab. Grand Junction, Colo. 1965-1966

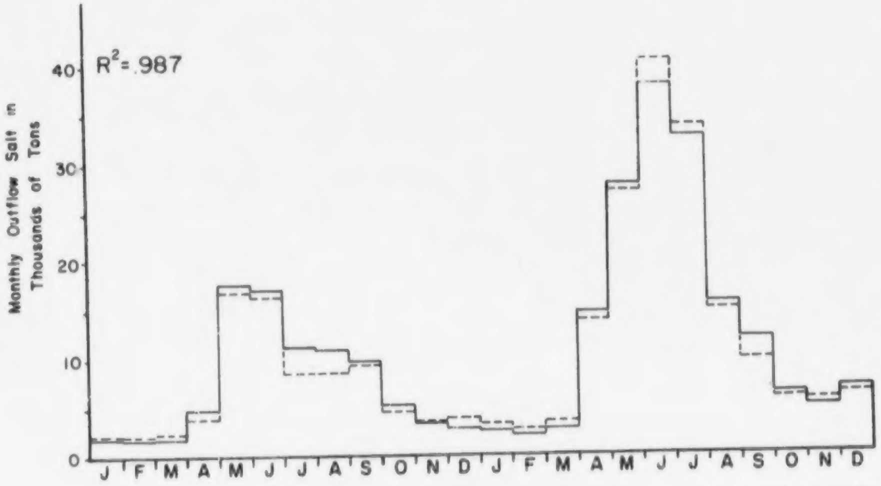


Salt Outflow – Gunnison River ab Grand Junction, Colo. 1965-1966

Figure H28. Computed and recorded water and salt outflow graphs of the Gunnison River above Grand Junction, Colorado.

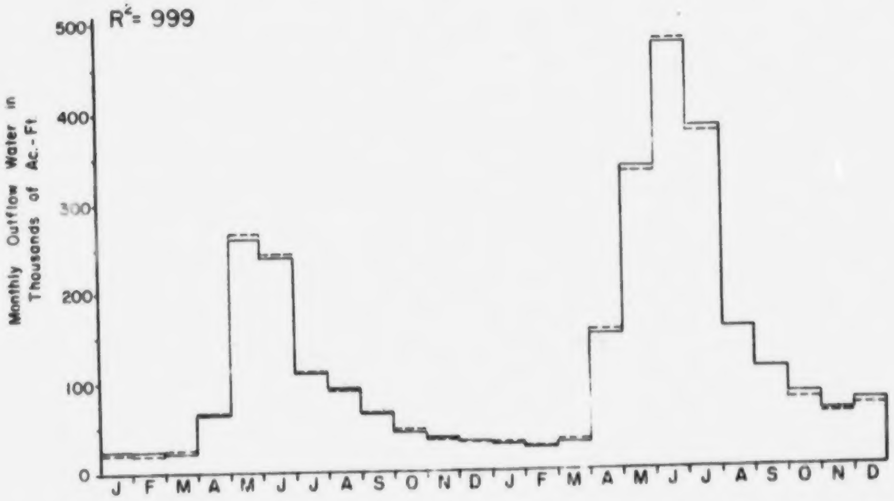


Outflow Hydrograph – Gunnison River ab. Gunnison, Colo. 1964-1965

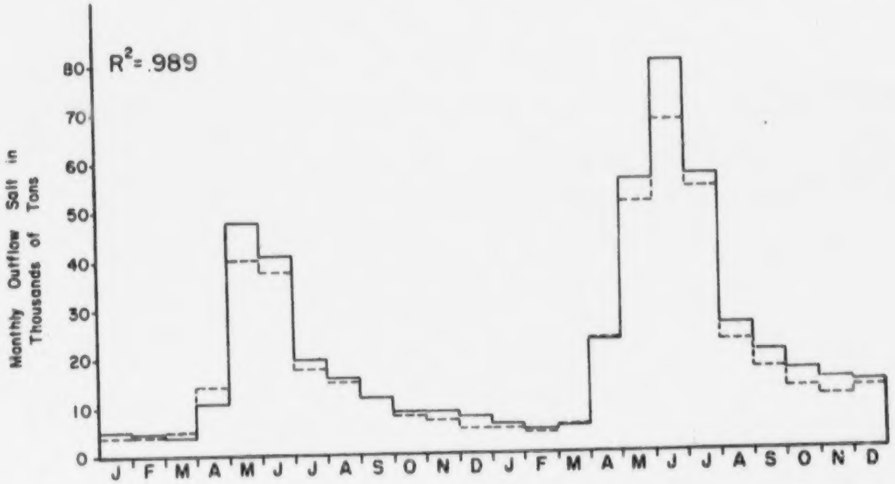


Salt Outflow – Gunnison River ab. Gunnison, Colo. 1964-1965

Figure H25. Computed and recorded water and salt outflow graphs of the Gunnison River above Gunnison, Colorado.

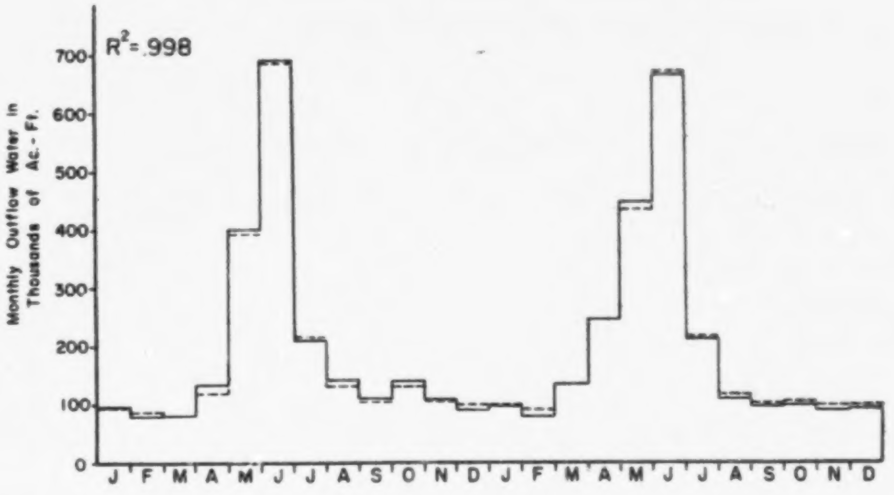


Outflow Hydrograph – Gunnison River ab North Fork Gunnison R. 1964-1965

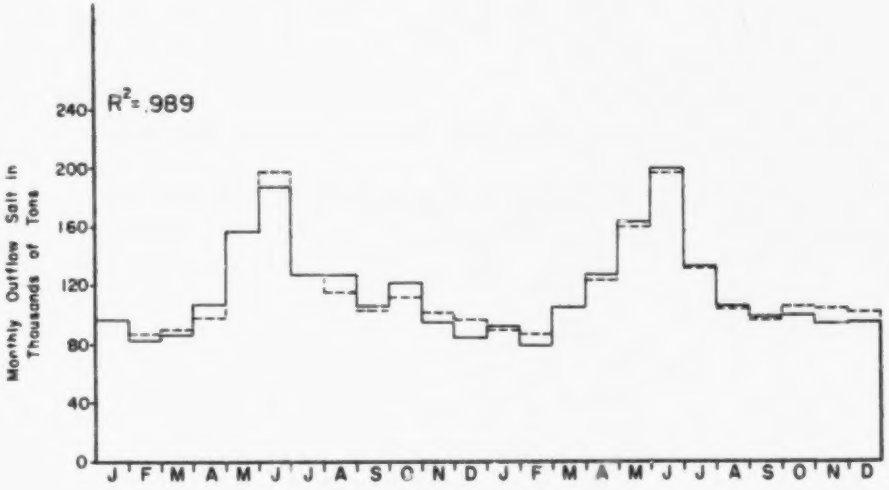


Salt Outflow – Gunnison River ab. North Fork Gunnison R. 1964-1965

Figure H26. Computed and recorded water and salt outflow graphs of the Gunnison River above North Fork Gunnison River.

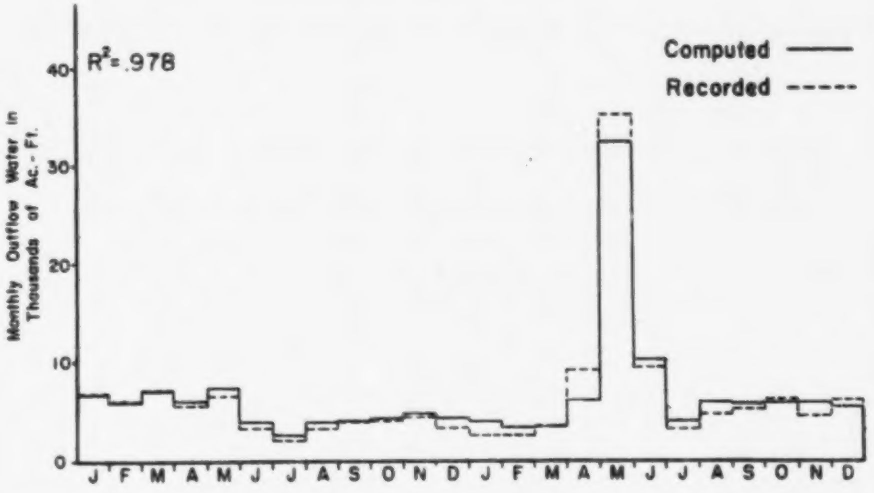


Outflow Hydrograph – Colorado River ab. Plateau Creek 1959-1960

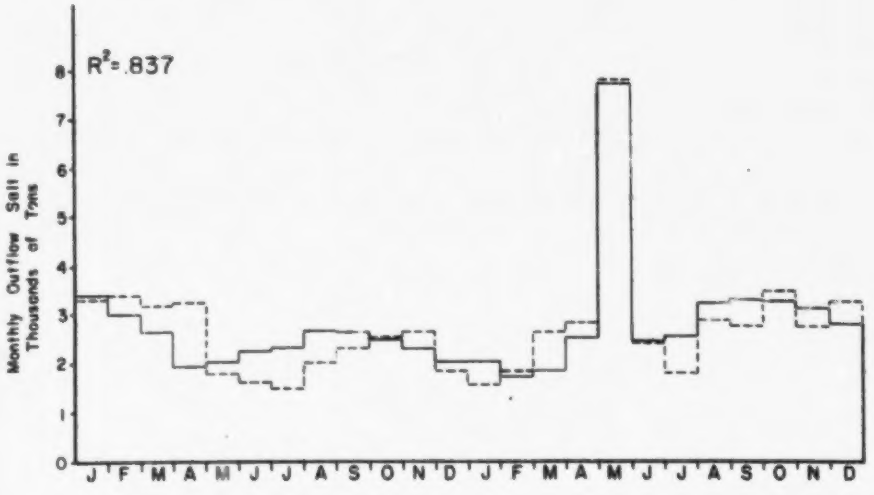


Salt Outflow – Colorado River ab. Plateau Creek 1959-1960

Figure H23. Computed and recorded water and salt outflow graphs of the Colorado River above Plateau Creek.

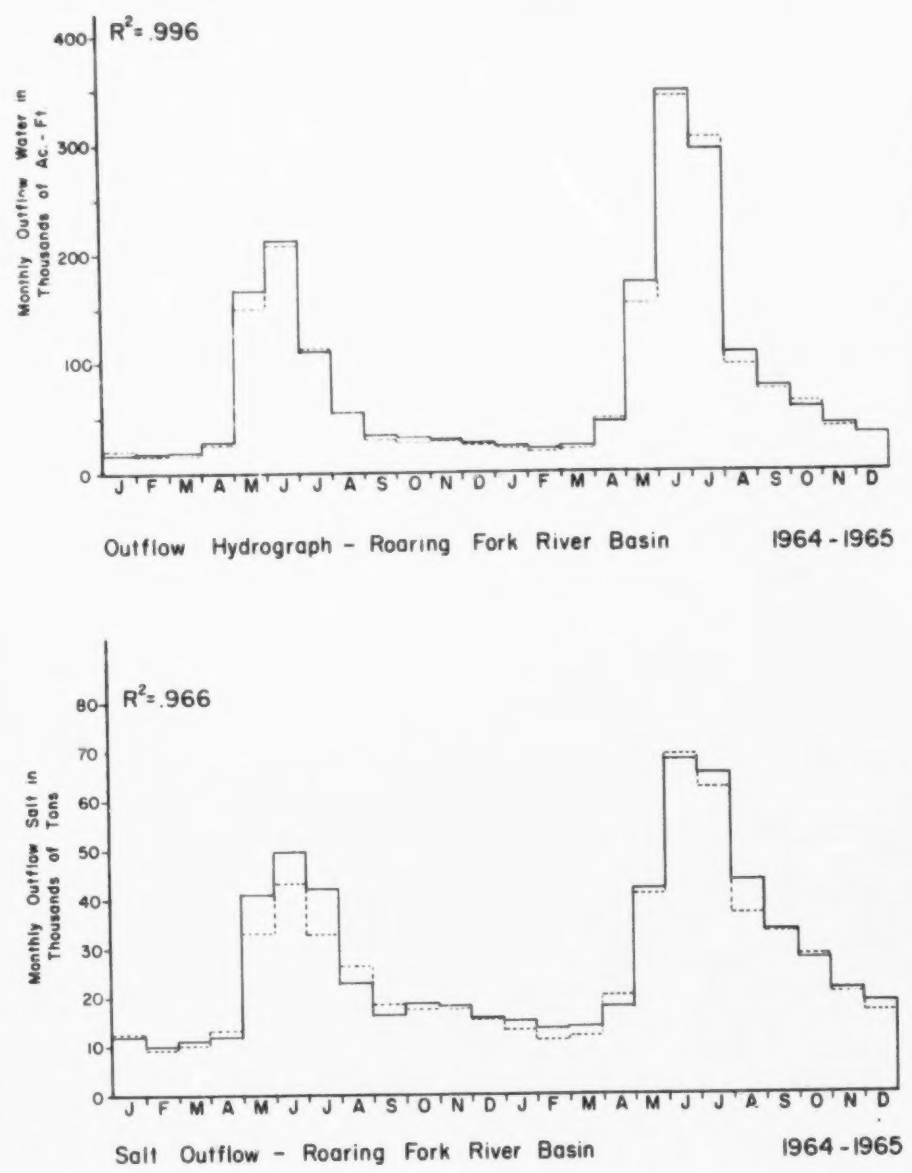


Outflow Hydrograph – Plateau Creek Basin 1963-1964



Salt Outflow – Plateau Creek Basin 1963-1964

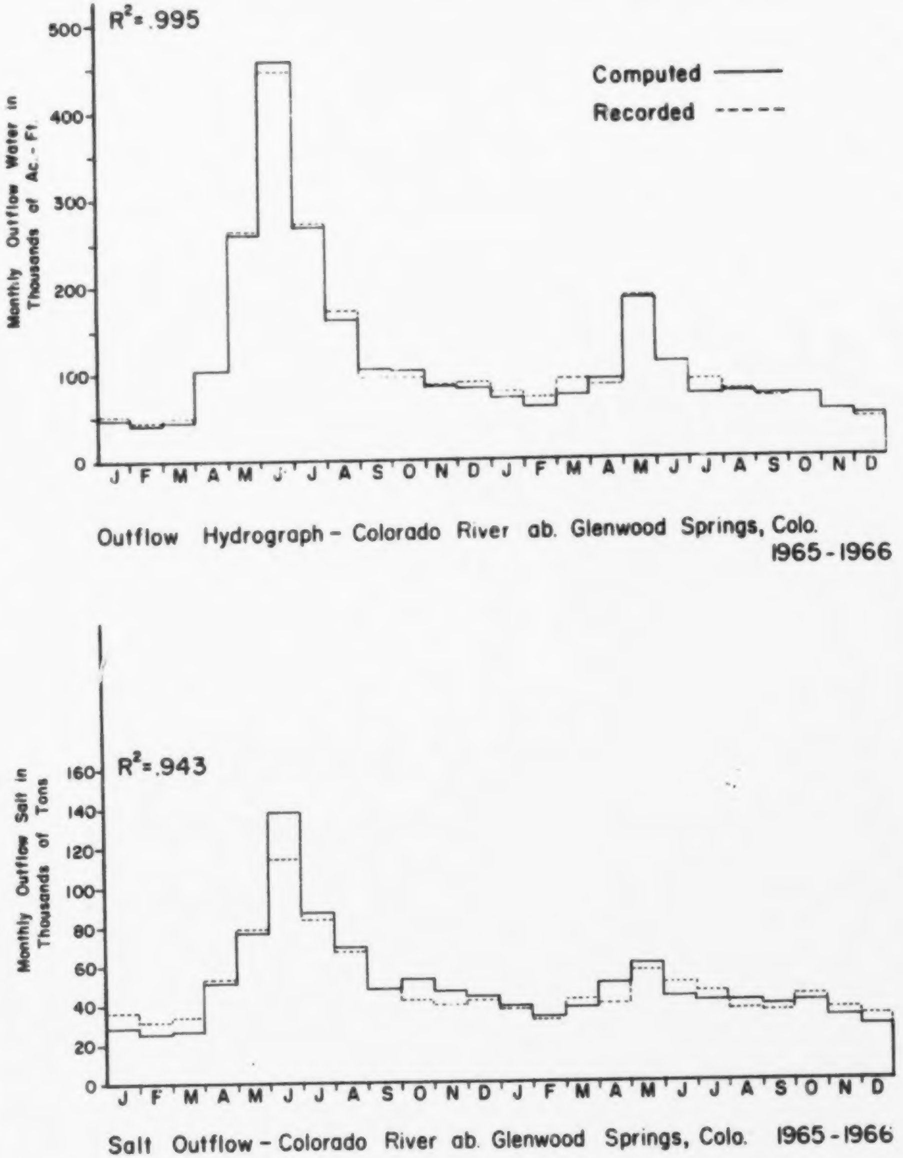
Figure H24. Computed and recorded water and salt outflow graphs of the Plateau Creek basin.



Outflow Hydrograph - Roaring Fork River Basin 1964-1965

Salt Outflow - Roaring Fork River Basin 1964-1965

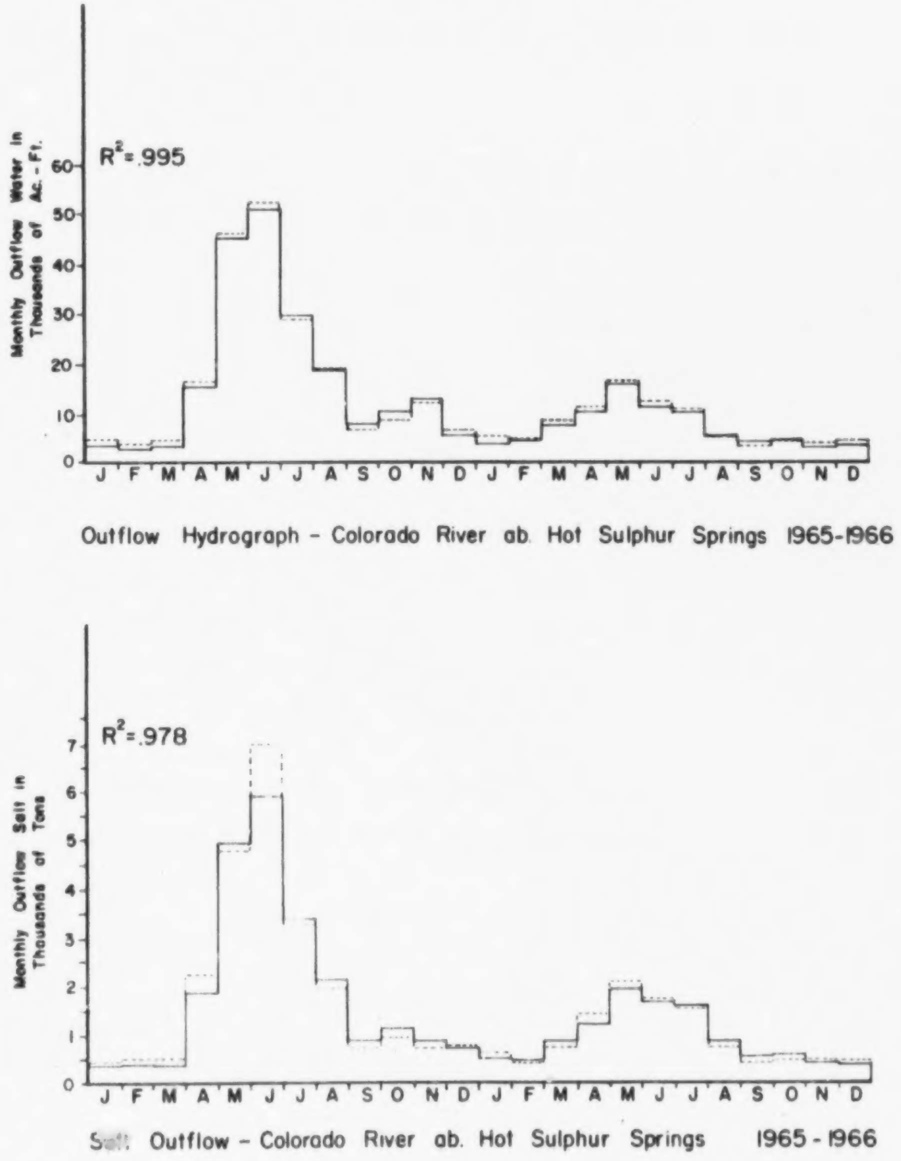
Figure H21. Computed and recorded water and salt outflow graphs of the Colorado River above Glenwood Springs, Colorado.



Outflow Hydrograph - Colorado River ab. Glenwood Springs, Colo. 1965-1966

Salt Outflow - Colorado River ab. Glenwood Springs, Colo. 1965-1966

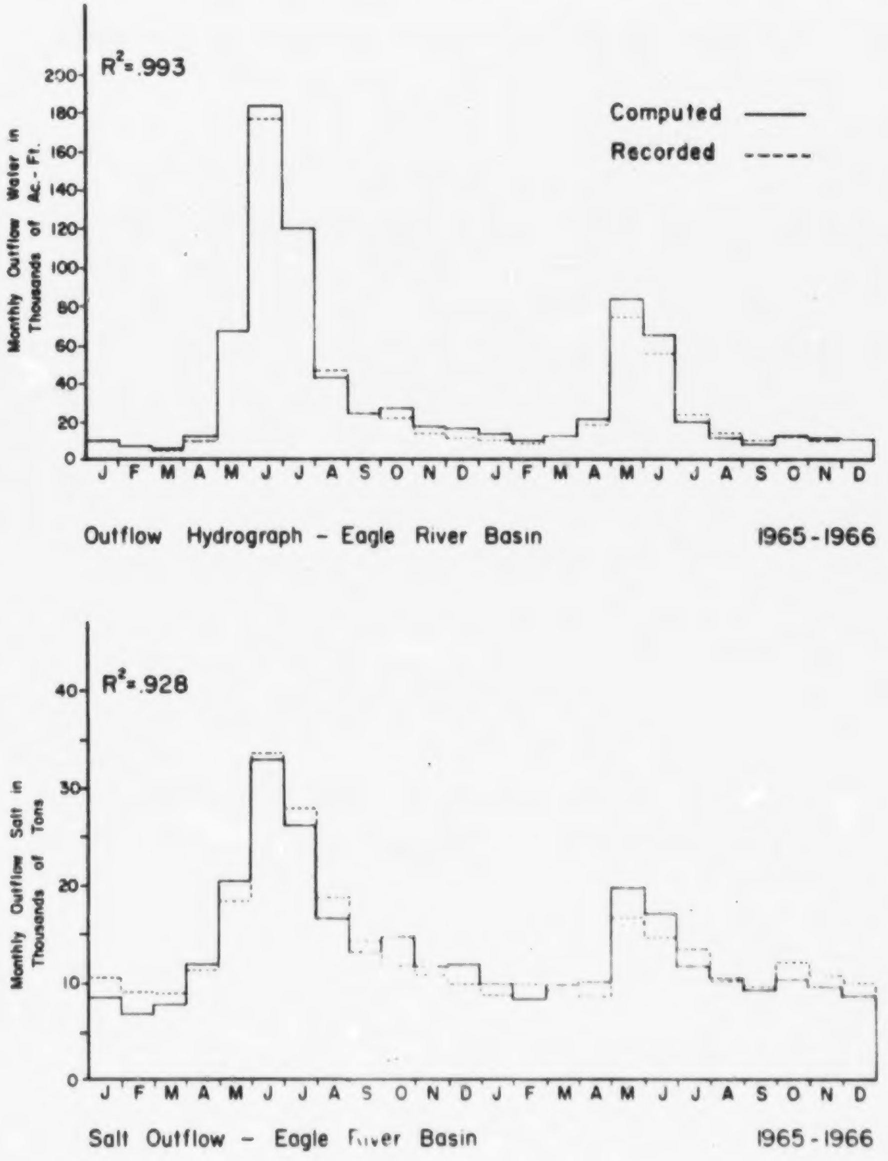
Figure H22. Computed and recorded water and salt outflow graphs of the Roaring Fork River basin.



Outflow Hydrograph - Colorado River ab. Hot Sulphur Springs 1965-1966

Salt Outflow - Colorado River ab. Hot Sulphur Springs 1965 - 1966

Figure H19. Computed and recorded water and salt outflow graphs of the Colorado River above Hot Sulphur Springs.



Outflow Hydrograph - Eagle River Basin 1965-1966

Salt Outflow - Eagle River Basin 1965 - 1966

Figure H20. Computed and recorded water and salt outflow graphs of the Eagle River basin.

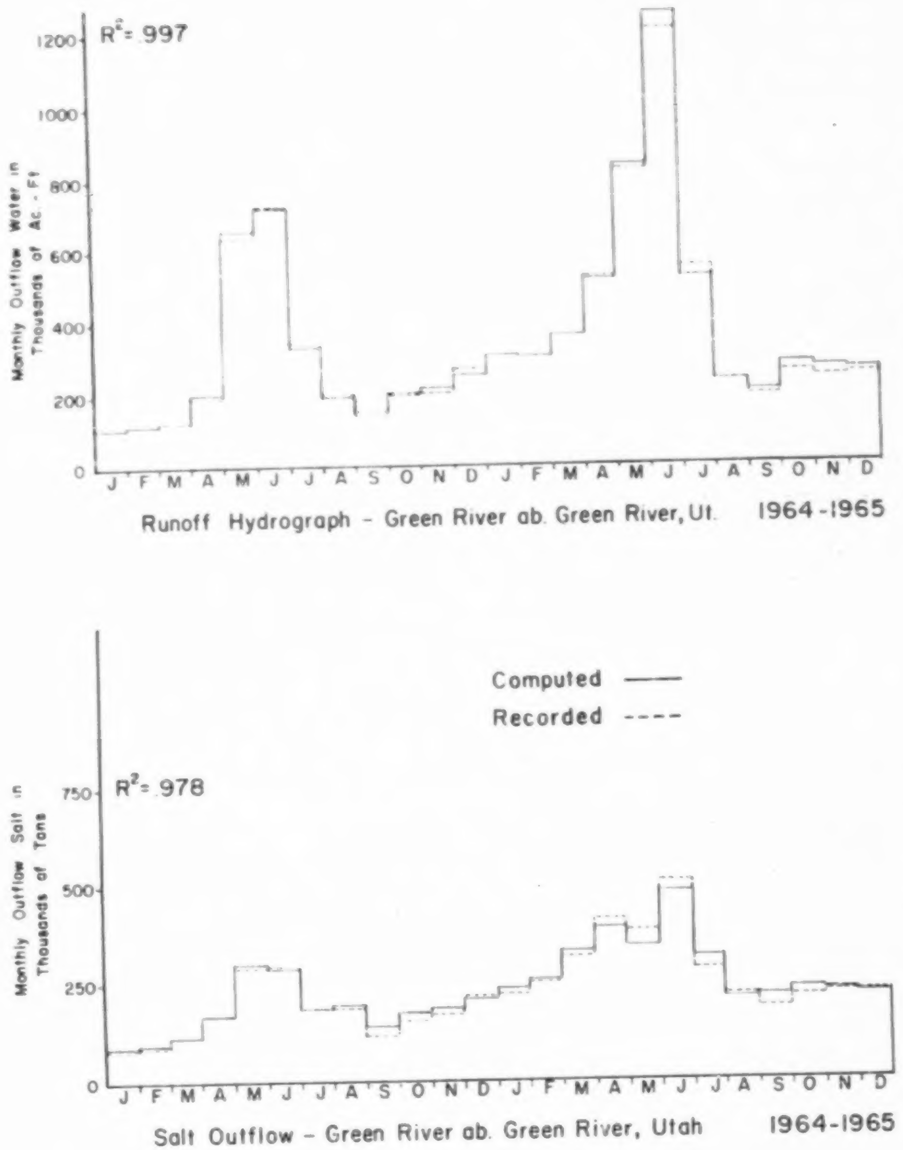


Figure H17. Computed and recorded water and salt outflow graphs of the Green River above Green River, Utah.

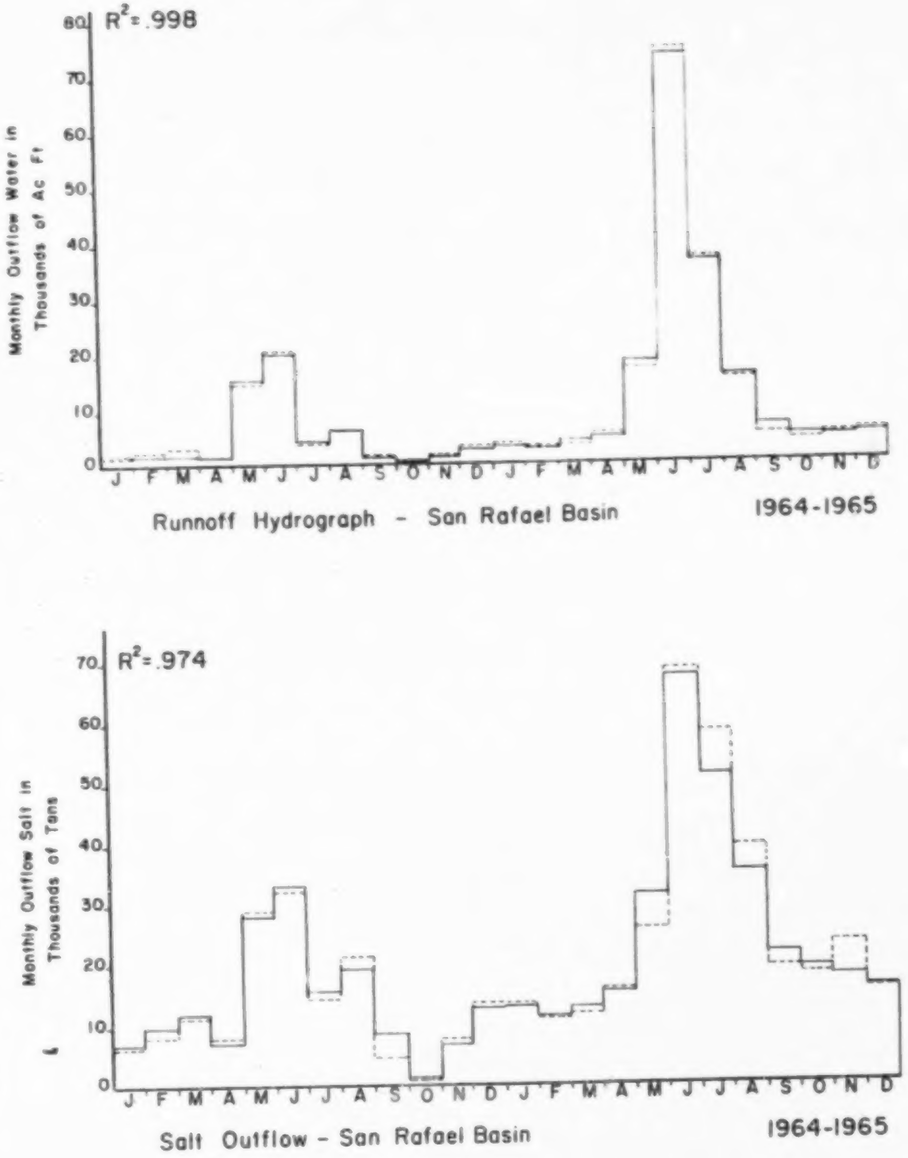
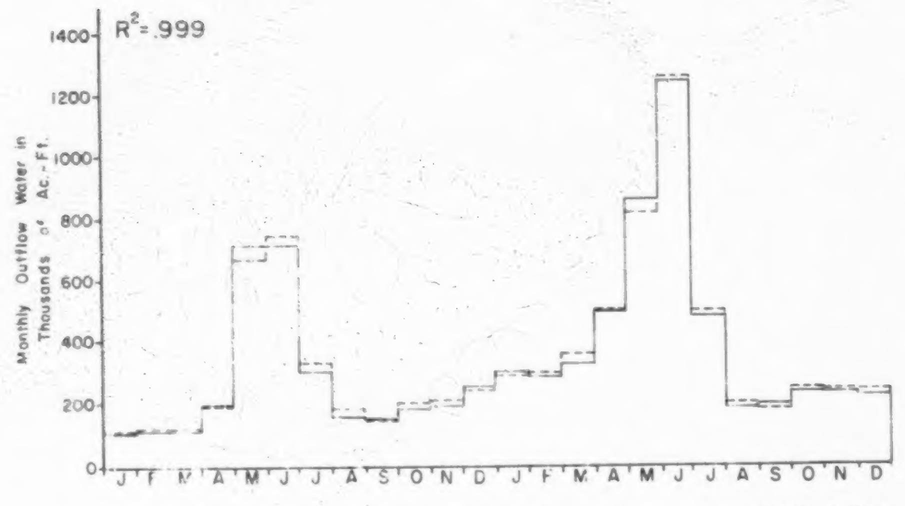
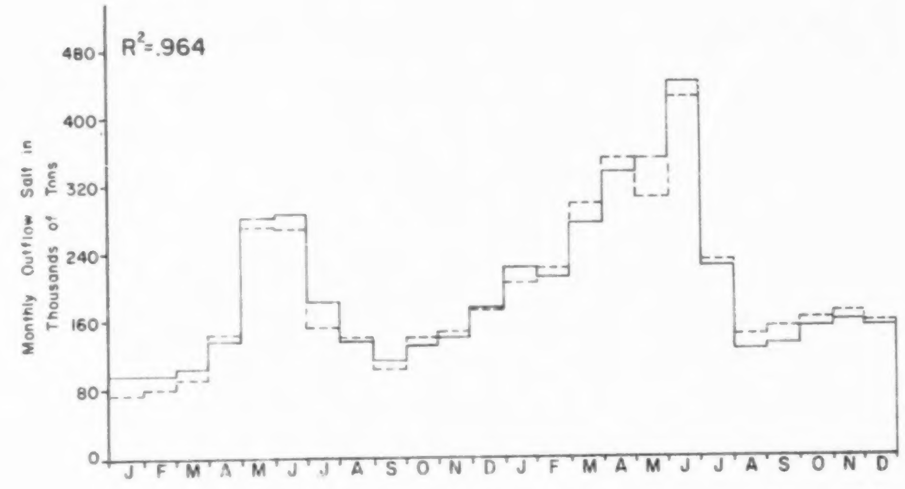


Figure H18. Computed and recorded water and salt outflow graphs of the San Rafael basin.

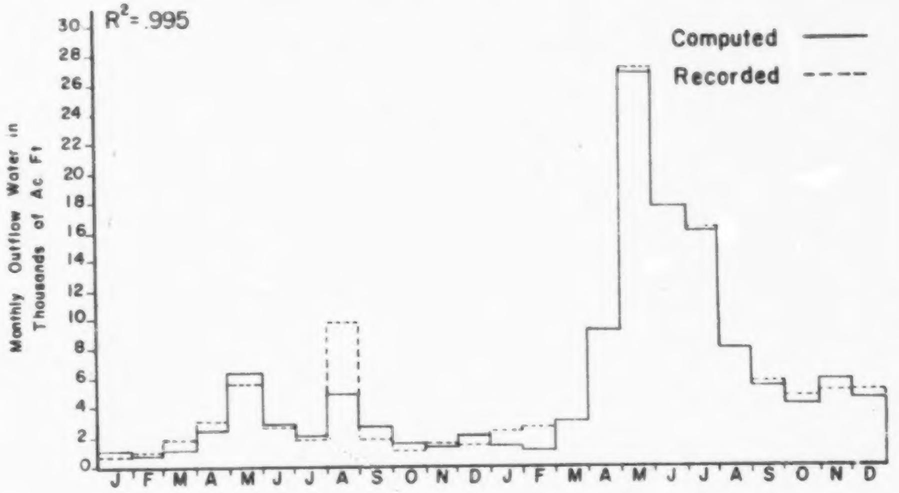


Runoff Hydrograph - Green River Above Ouray, Ut. 1964-1965

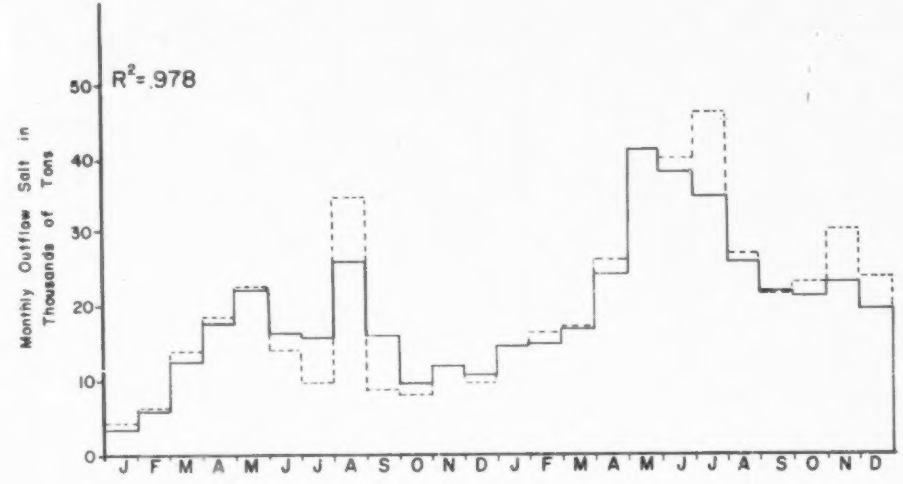


Salt Outflow - Green River Above Ouray, Ut. 1964-1965

Figure H15. Computed and recorded water and salt outflow graphs of the Green River above Ouray, Utah.

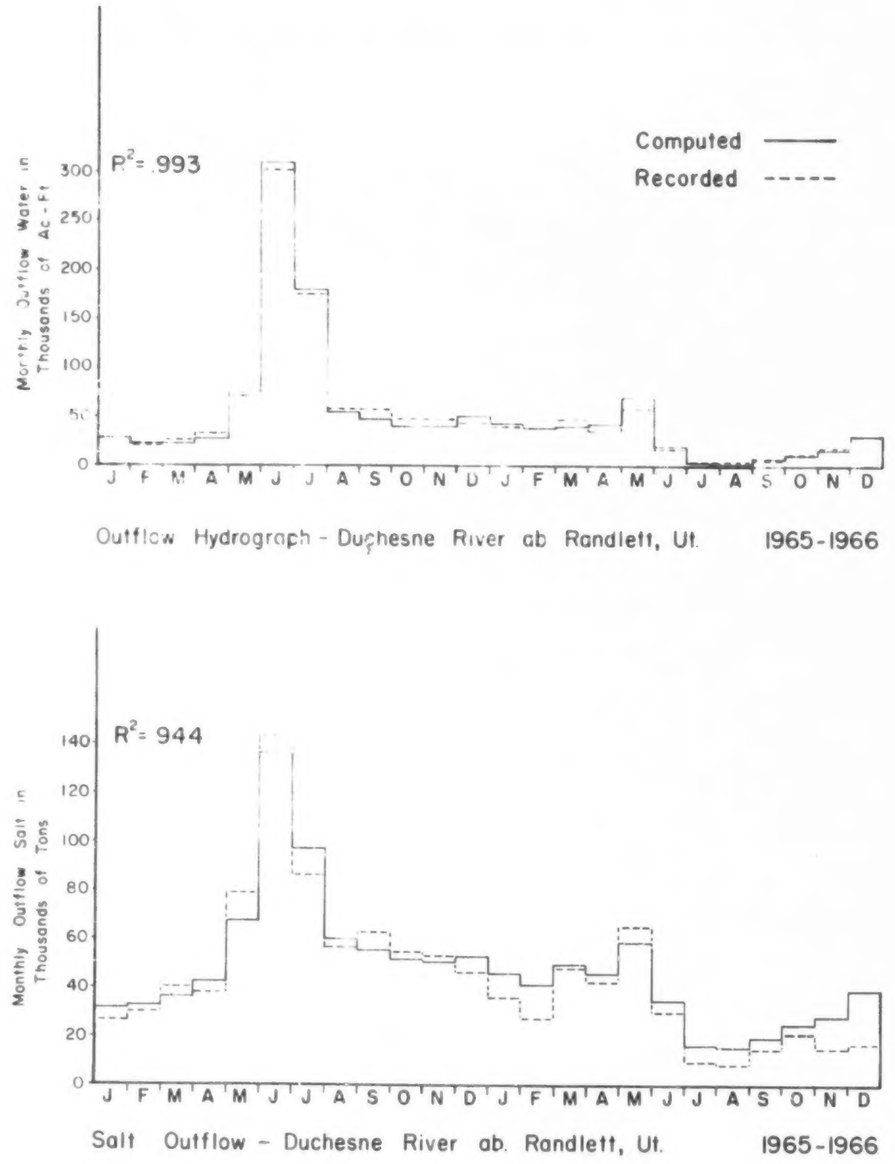


Runoff Hydrograph - Price River Basin 1964-1965



Salt Outflow - Price River Basin 1964-1965

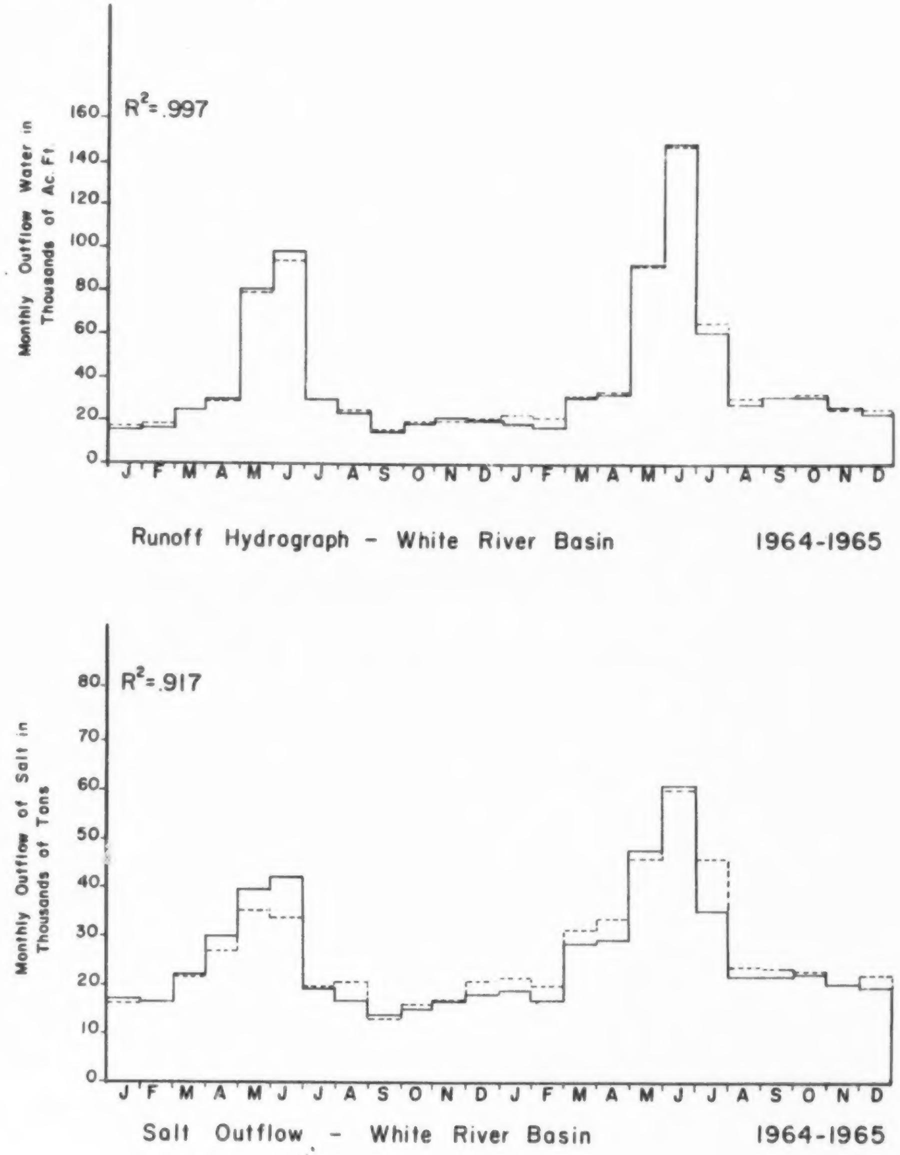
Figure H16. Computed and recorded water and salt outflow graphs of the Price River basin.



Outflow Hydrograph - Duchesne River ab Randlett, Ut. 1965-1966

Salt Outflow - Duchesne River ab. Randlett, Ut. 1965-1966

Figure H13. Computed and recorded water and salt outflow graphs of the Duchesne River above Randlett, Utah.



Runoff Hydrograph - White River Basin 1964-1965

Salt Outflow - White River Basin 1964-1965

Figure H14. Computed and recorded water and salt outflow graphs of the White River basin.

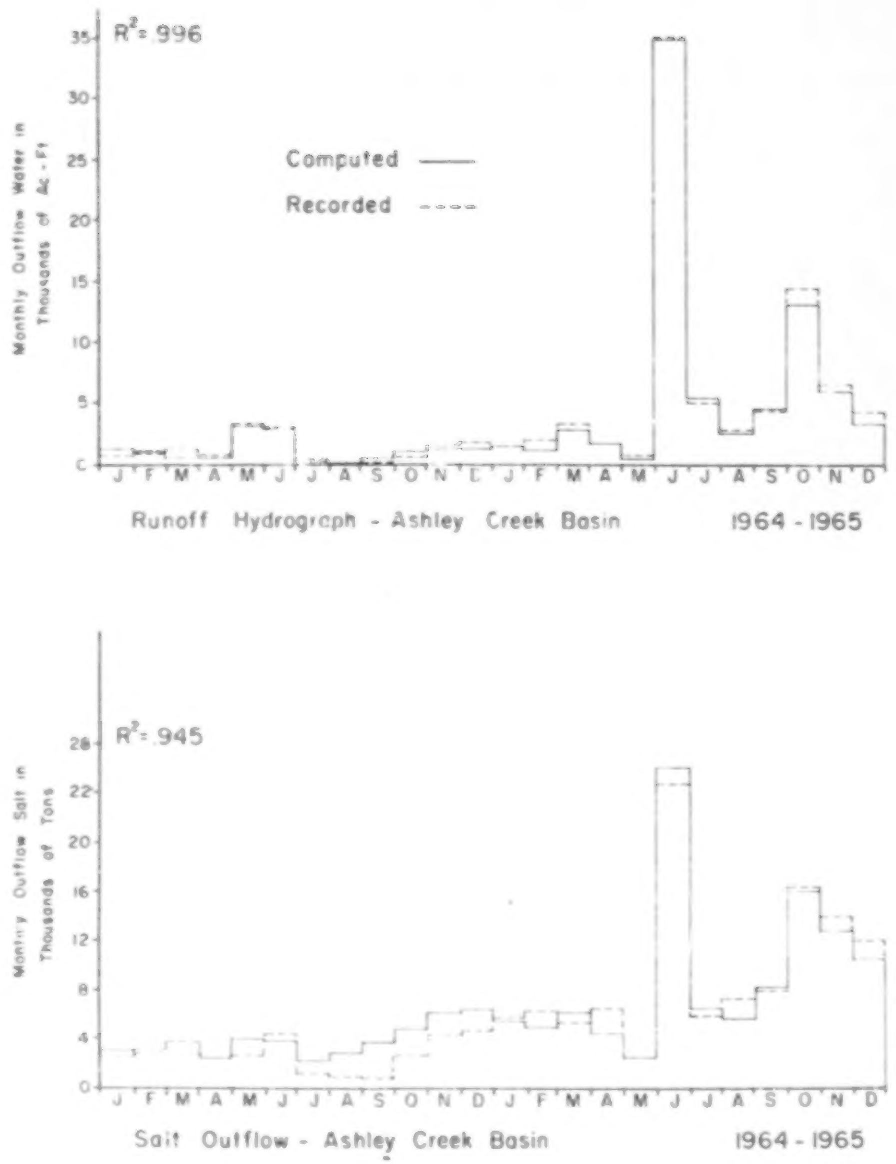


Figure H11. Computed and recorded water and salt outflow graphs of the Ashley Creek basin.

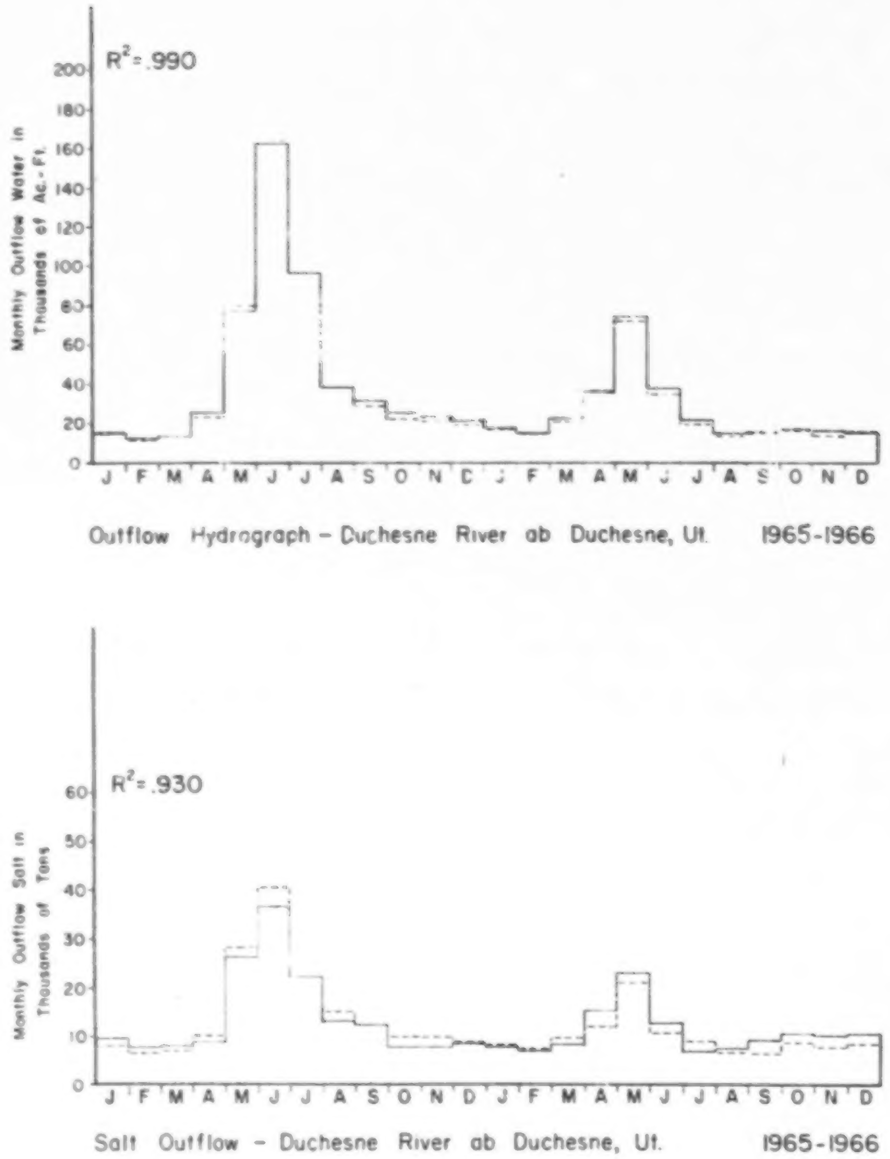


Figure H12. Computed and recorded water and salt outflow graphs of the Duchesne River above Duchesne, Utah.

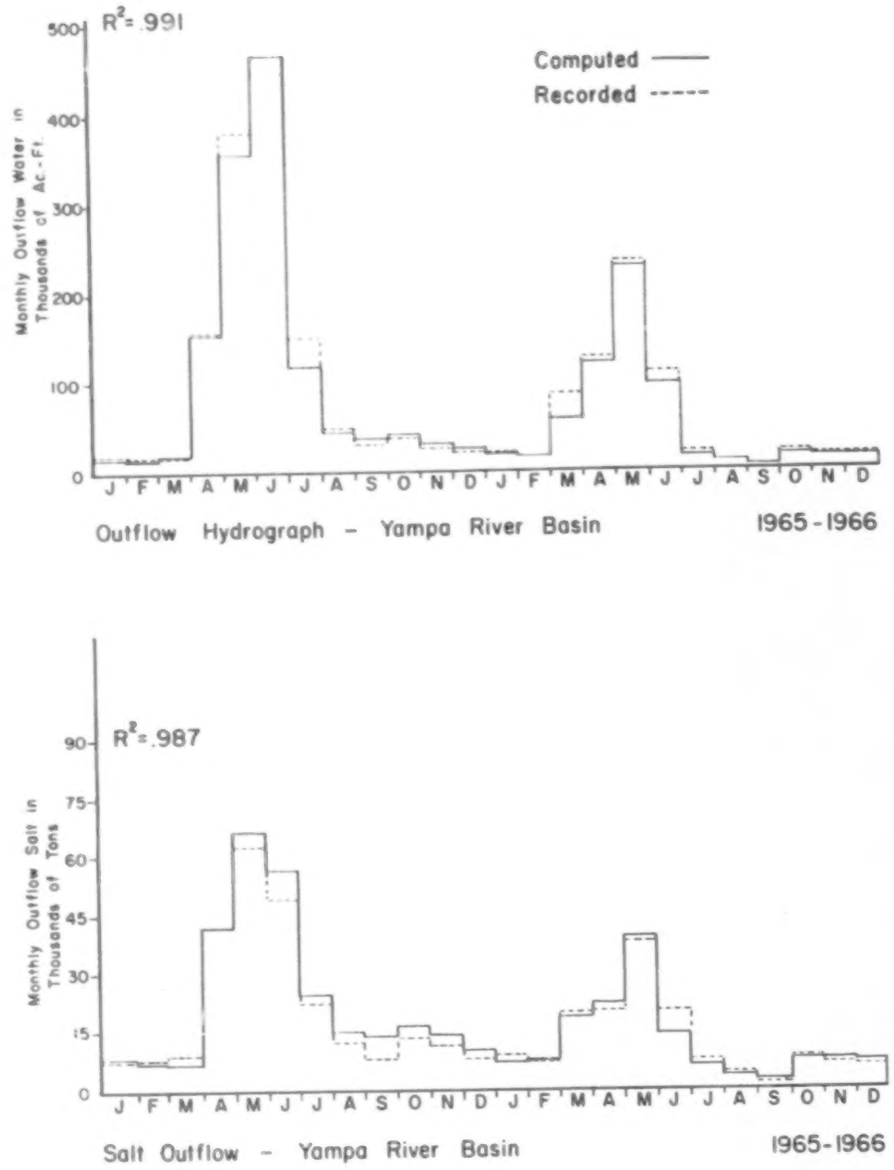


Figure H9. Computed and recorded water and salt outflow graphs of Yampa River basin.

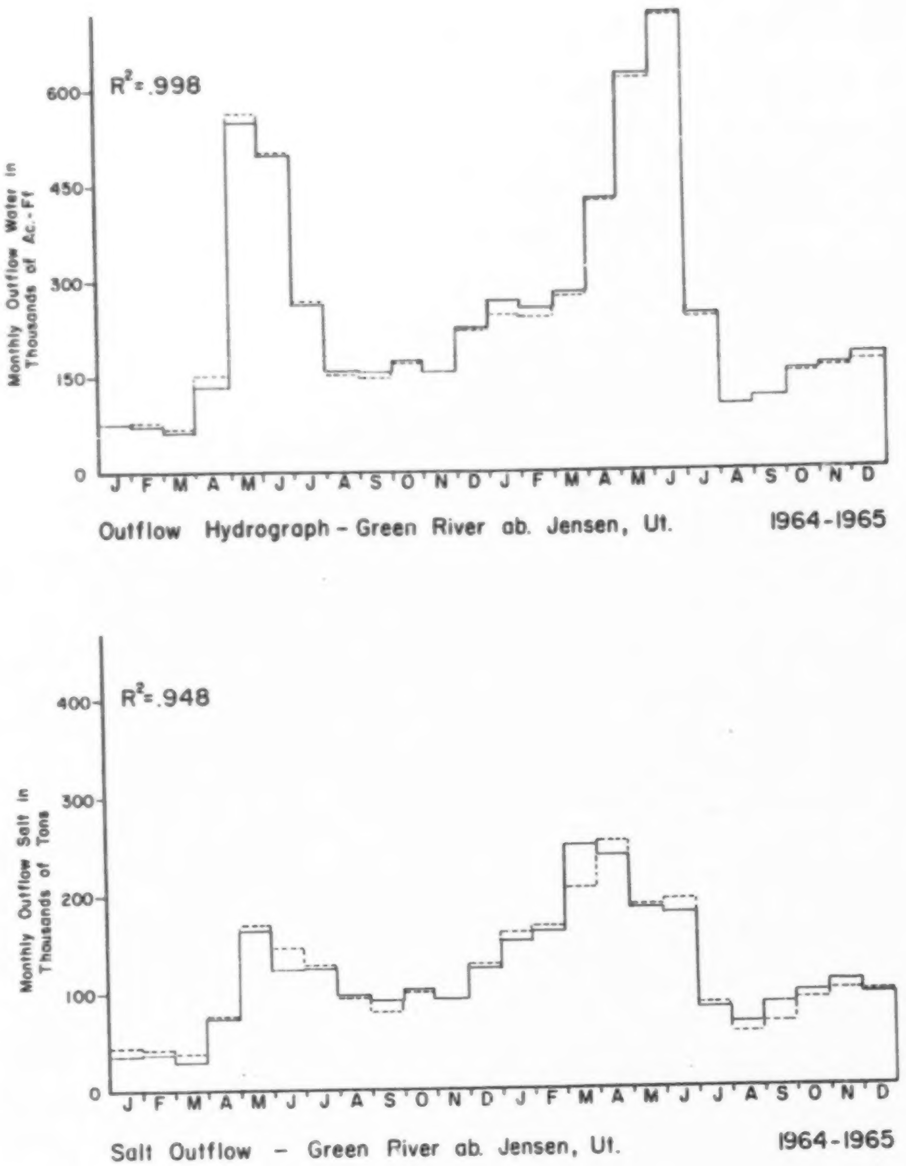


Figure H10. Computed and recorded water and salt outflow graphs of Green River above Jensen, Utah.

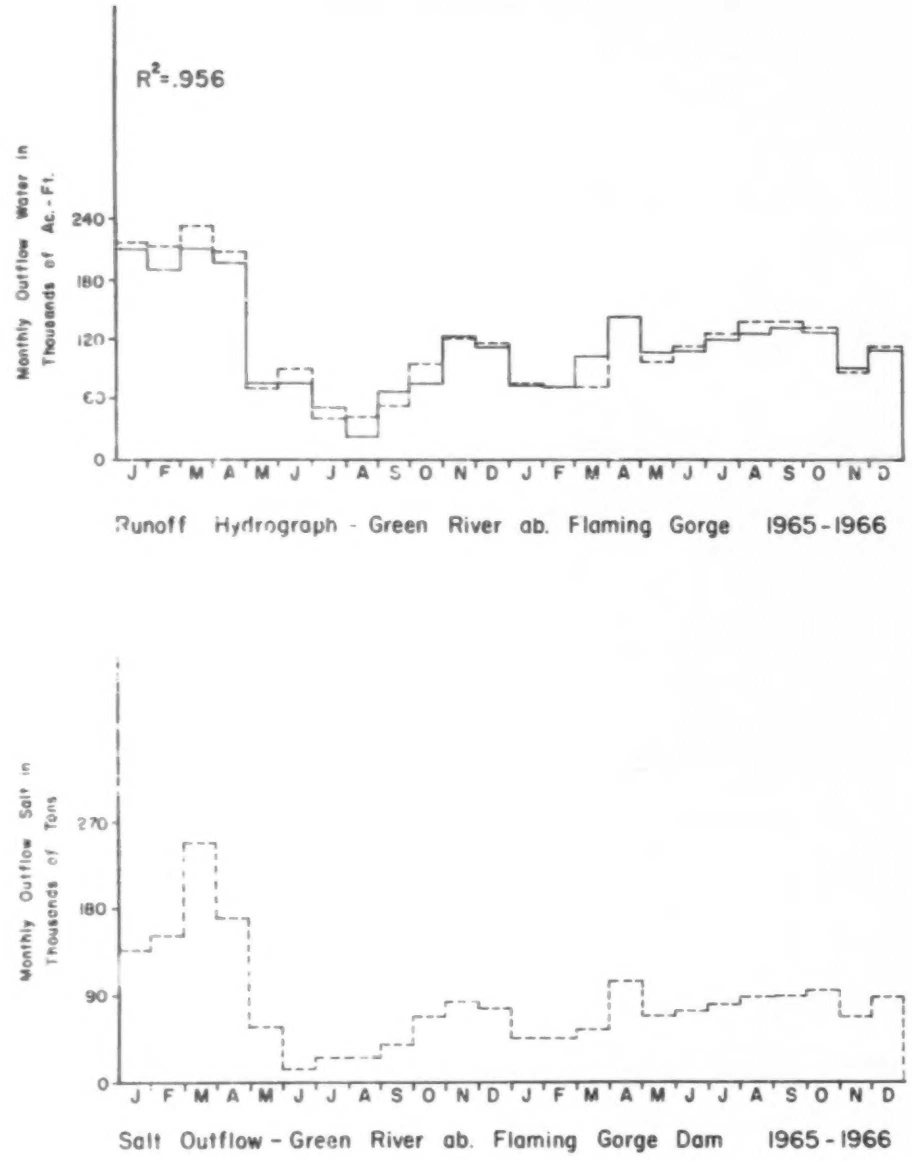


Figure H7. Computed and recorded water and salt outflow graphs of Green River above Flaming Gorge Dam.

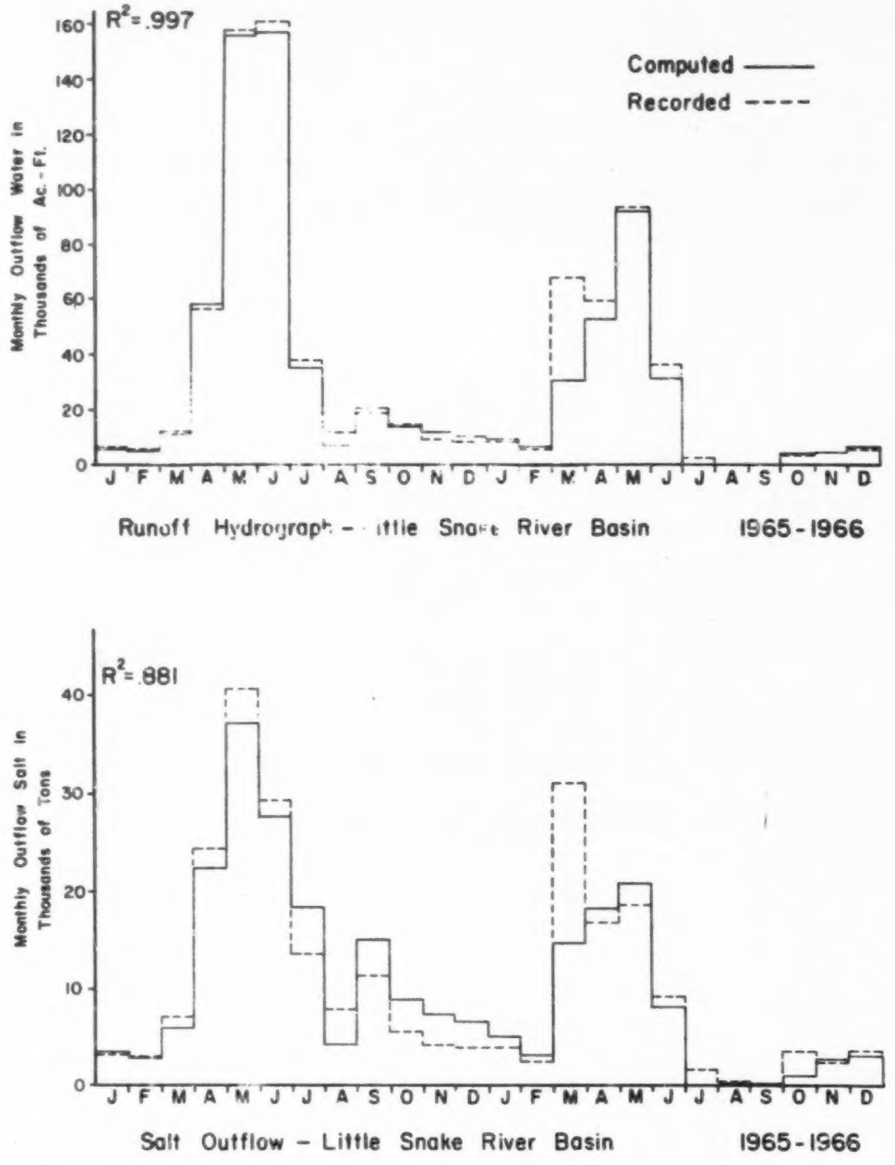
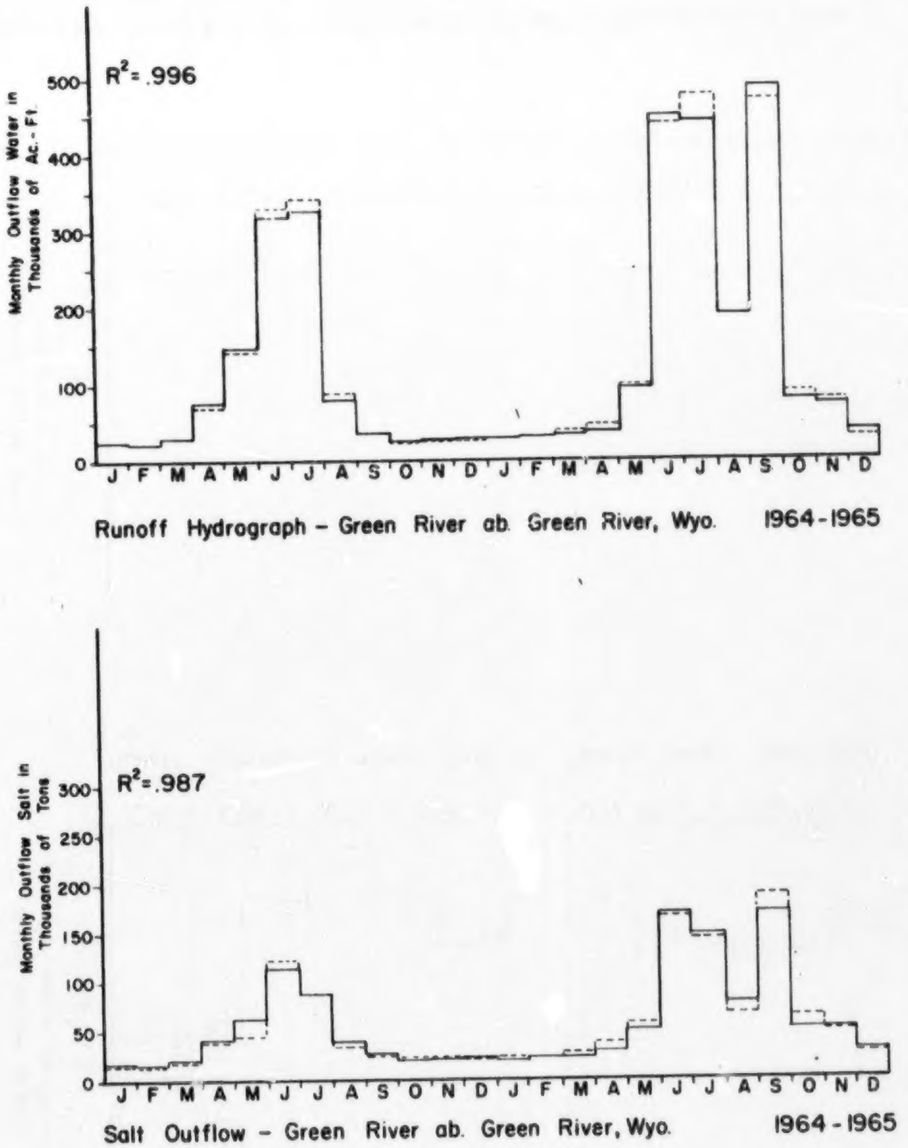


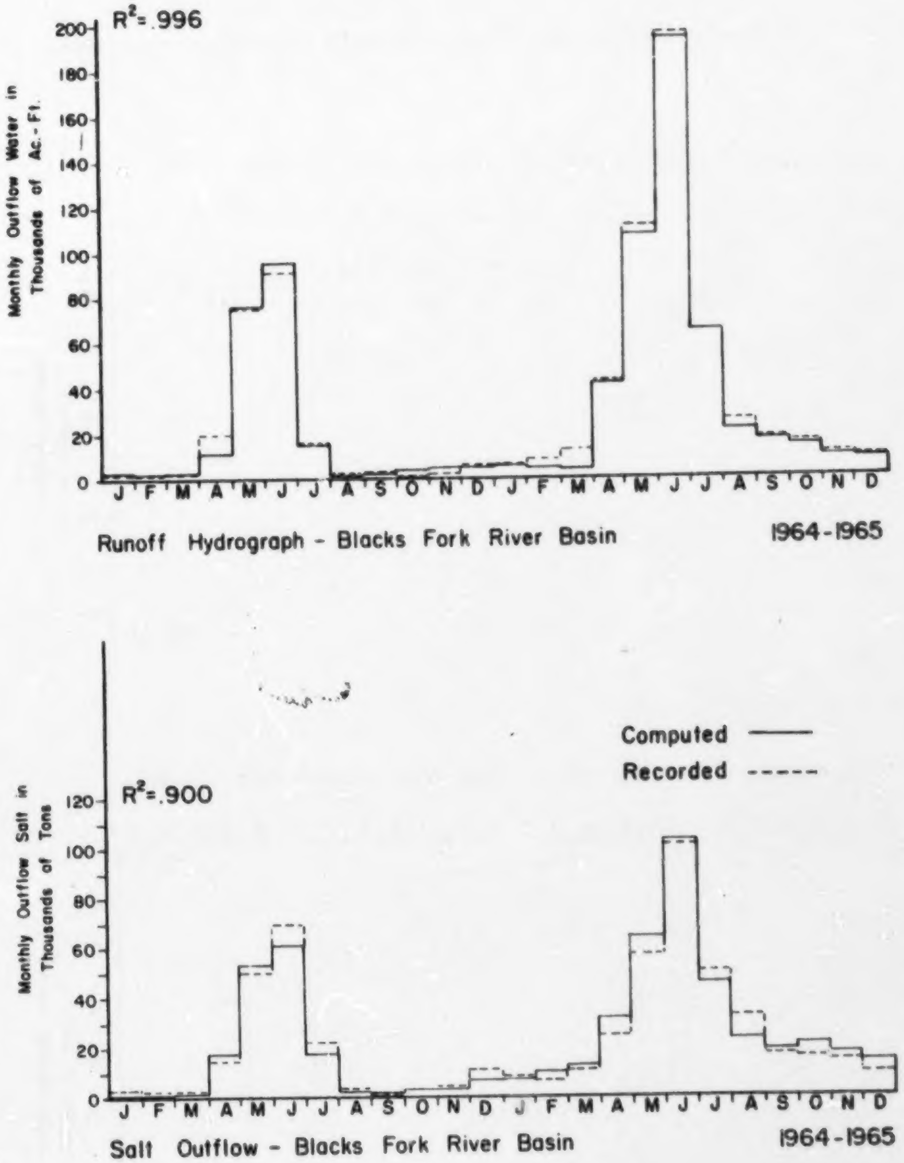
Figure H8. Computed and recorded water and salt outflow graphs of Little Snake River basin.



Runoff Hydrograph – Green River ab. Green River, Wyo. 1964-1965

Salt Outflow – Green River ab. Green River, Wyo. 1964-1965

Figure H5. Computed and recorded water and salt outflow graphs of Green River above Green River, Wyoming.



Runoff Hydrograph – Blacks Fork River Basin 1964-1965

Salt Outflow – Blacks Fork River Basin 1964-1965

Figure H6. Computed and recorded water and salt outflow graphs of Blacks Fork River basin.

Table H-3. Single constant input parameters or constant for the subbasins in the San Juan Division.

Subbasin	k_u	k_a	k_b	k_c	k_s	Efficiency (%)	M_{es} (inches)	M_{es} (inches)	k_d (%)	C_q (P.P.M.)	C_s'	C_{qa} (P.P.M.)	C (P.P.
San Juan River above Arboles, Colo.	0.26	0.08	0.90	-	3.0	46.5	2.0	5.0	-	400	1.21	200	-
San Juan River above Archuleta, N.M.	-	-	0.92	-	3.0	56.8	2.0	4.5	-	620	1.25	620	-
Animas River Basin	-	-	0.65	-	3.0	60	2.0	5.5	3.85	720	1.25	470	7
San Juan River above Farmington, N.M.	-	0.46	-	-	2.0	60	2.0	5.2	1.35	-	1.2	610	7
LaPlata River Basin	-	0.97	0.203	-	2.0	48	2.0	6.6	12.5	2,500	1.2	1,860	2,5
San Juan River above Shiprock, N.M.	-	0.80	-	-	2.0	60	2.0	5.5	-	-	1.15	900	-
San Juan River above Bluff, Utah	-	0.161	0.195	-	2.0	55.5	2.0	6.0	-	2,400	1.25	1,600	-
Colorado River above Lee's Ferry, Arizona	-	-	-	-	2.0	60	2.0	0.38	-	-	1.25	1,200	-

qa M.)	C_{oq} (P.P.M.)	m	n	Pot 5 (inches)	Pot 21		Pot 28		Pot 30		Pot 24		Delay A Agriculture (months)	Delay B Groundwater (months)
					Model 1 (inches)	Year 2 (inches)	Model 1 (inches)	Year 2 (inches)	Model 1 (inches)	Year 2 (inches)	Model 1 (inches)	Year 2 (inches)		
00	-	-0.14	54.3	2.22	0.41	6.39	7.0	10.5	-	-	4.0	4.7	1.5	-
20	-	-0.24	59.0	-	0.48	2.86	0.042	0.135	-	-	3.0	4.5	2.5	-
70	780	-0.61	1,517	-	1.16	1.27	0.20	0.23	0.05	0.06	5.0	5.2	2.5	3.0
10	760	-	-	2.00	0.19	1.15	0.08	0.08	0.02	0.02	3.0	3.9	2.5	2.5
60	2,540	-0.45	132.6	2.35	1.45	1.64	0.7	1.0	0	2.8	0	1.5	2.5	2.5
00	-	-	-	0.75	0.12	1.09	0.09	0.09	-	-	2.9	5.2	2.0	-
00	-	-0.41	143	1.44	0.38	1.34	0.06	0.06	-	-	2.8	2.1	4.5	-
00	-	-	-	-	0.26	0.55	0.01	0.01	-	-	1.5	1.5	3.0	-

H-7- H-8